Identifying the connection between groundwater nutrients and stable isotopes in the ridge-slough-tree island community at Loxahatchee Impoundment Landscape Assessment (LILA)

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I. Executive Summary

This report fulfills Task 5 *Final Report* of PO# 4500031463 and summarizes all groundwater and surface water data collected between October 2008 and May 2009. The three main objectives of this study were to determine: 1) if nutrient availability in tree islands varies with seasonal hydrodynamics; 2) how hydrologic conditions and shallow groundwater chemistry differ in tree islands with peat versus limestone cores; and 3) if shallow groundwater chemistry differs with varying evapotranspiration rates within the tree islands and the adjacent ridge-and-slough community at Loxahatchee Impoundment Landscape Assessment (LILA). In order to achieve the project objectives, groundwater and surface water samples were collected across high to low density tree-planting transects. Thirty groundwater samples and eight surface water samples were collected per sampling event using a peristaltic pump. Temperature, conductivity, pH and dissolved oxygen measurements were made in the field. Water samples were analyzed for alkalinity, anions, cations, stable isotopes of oxygen and hydrogen, and total and dissolved nutrients (nitrogen, carbon and phosphorus) in the lab. In addition, stem water and soil water samples were taken on six of the tree islands at LILA (M1E, M1W, M2E, M2W, M3W, and M4W) for stable isotopes of oxygen and hydrogen.

Surface water chemistry at LILA was characterized by low concentrations of major ions and low nutrient concentrations for the most part, except for chloride and sodium during the dry season. In general, the groundwater chemistry in the tree islands had the highest concentrations of major ions and nutrients as compared to the groundwater from the ridge and slough. The isotopic compositions of hydrogen (deuterium, δD) and oxygen ($\delta^{18}O$) of the surface water varied significantly from the wet to the dry season, while the isotopic composition of the groundwater tended to be more stable. The slough groundwater was enriched in the (heavy) stable isotopes of oxygen and hydrogen as compared to ridge groundwater indicating a higher interaction with the overlying surface water. Furthermore, the isotopic composition of the groundwater in the tree islands was depleted as compared to the surface water and the ridge and slough groundwater suggesting greater inputs from rainfall.

Differences in the groundwater chemistry were observed between tree island types, between the edge and center of the tree islands, and between different planting years. The groundwater along the edges of the tree islands tended to have lower major ion concentrations and higher isotope values compared to the groundwater in the center of the tree islands, suggesting an increase in groundwater-surface water interactions along the edges of the tree islands. In the three previous sampling events the isotopic values of the groundwater of tree islands planted in 2006 were significantly lower than those planted in 2007. This suggested that two different mechanisms were influencing groundwater-surface water interactions. In May of 2009, the isotopic values of the groundwater in all the islands were similar and suggested that the islands were undergoing similar processes. The isotopic composition of the stem water suggested a shift in plant water interactions on tree islands planted in 2007 from the wet to the dry season. During the wet season the trees in the center of the Planting-2 islands relied on

soil water while during the dry season they relied more on groundwater, while those from Planting-1 relied on groundwater in both the wet season and dry season.

II. Background

In many wetlands around the world, groundwater-surface water interactions strongly influence the chemistry of shallow groundwater and the location and patterns of vegetation (Ferone and Devito 2004, Glaser et al. 1981, Rietkerk et al. 2004). Similar to the Everglades, these wetlands are sensitive to long term shifts in surface level due to their low topographic relief. In the Everglades, only about one meter separates the bottom of a slough and the top of a tree island but the underlying groundwater chemistry differs significantly. Gann et al. (2005) detected total soil phosphorus concentrations that were six-fold higher in tree islands (78 μg/g to 446 μg/g) as compared to the adjacent marsh. Ross et al. (2006) detected concentrations of soluble reactive phosphorus (SRP) in the tree island pore water to be two to three orders of magnitude higher than the surrounding marsh. Wetzel et al. (2005) proposed that the high phosphorus concentrations detected in tree islands maybe attributed to inputs of bird guano and high differential evapotranspiration rates that increased inputs of high nutrient groundwater.

The correlation between higher order vascular plants and increased nutrients is not unique to the Everglades. Similar relationships between raised ridges or islands with elevated ion and nutrient groundwater concentrations and surrounding hollows and sloughs with low nutrient and ion concentrations have been seen in the Great Vasyugan Bog, the Okavango Delta and many North American peatlands. These landscape and nutrient patterns have been attributed to localized areas of nutrient rich groundwater discharge and/or high evapotranspiration rates that effectively concentrate nutrients and ions (Eppinga et al. 2008, McCarthy 1998, Glaser et al. 1997). Even within a tree island, total soil phosphorus concentrations appear to be correlated to elevation, with 1600 μg/g detected in the most elevated areas, Hardwood Hammocks; 640 μg/g detected in areas that are partially flooded, Bayheads; and 510 μg/g detected in areas that are flooded year-round, Bayhead Swamp (Wetzel et al 2005). The variation in nutrient concentrations between these sections of a tree island may be attributed to differences in groundwater-surface water interactions and vegetation.

In many of the North American peatlands, the driving force behind this landscape patterning has been attributed to groundwater flow reversal and regional and local groundwater flow patterns. Romanowicz et al. (1993) recorded convergent and downward groundwater flow in raised bogs when water levels were higher than the surface of the bog. As surface waters dropped, they noted the direction of groundwater flow reversed to flow upward and divergent from the bog center. They attributed this groundwater flow reversal to the production of methane gas that caused groundwater beneath the raised bog to become over pressurized and therefore reverse the flow of the groundwater. Siegel and Glaser (1987) found that variations in the underlying geology led to areas of high nutrient groundwater discharge under raised bogs in the Lake Agassiz Peatlands in northern Minnesota. Harvey et al. (2000) has also noted upward flow of groundwater in tree islands in Water Conservation Area 3 during the dry season. This upward groundwater flow could bring high nutrient groundwater to tree islands. In addition, Ewe et al. (1999) also detected a seasonal shift in the utilization of groundwater and surface water in tree species located on hardwood hammock tree islands using oxygen and hydrogen stable isotopes. Ewe found that during the wet season, the water utilized by trees was about 0.8% groundwater, while during the dry season the water used was 86% groundwater. This seasonal shift, long term groundwater-surface water interactions and variable evapotranspiration rates may play a significant role in the concentration of phosphorus in tree islands.

To gain a further understanding of how groundwater-surface water interactions and evapotranspiration affect the groundwater chemistry of tree islands, ridges and sloughs, an investigation was conducted at Loxahatchee Impoundment Landscape Assessment (LILA). The three main objectives of this study were to determine: 1) if nutrient availability in tree islands varies with seasonal hydrodynamics; 2) how hydrologic conditions and shallow groundwater chemistry differ in tree islands with peat versus limestone cores; and 3) if shallow groundwater chemistry differs with varying evapotranspiration rates within the tree islands and the adjacent ridge-and-slough community. To achieve this goal, groundwater and surface water were collected for the analysis of nutrient and mineral constituents that could indicate the geochemical and hydrological pathways of the shallow groundwater. In addition, to determine the relationship between evapotranspiration rates and groundwater-surface water interactions, stem water was analyzed to identify the source of water taken up by the trees.

III. Study Area

The Loxahatchee Impoundment Landscape Assessment (LILA) was created in 2003 to provide a platform for the study of Everglades landscape patterns, wildlife, and hydrology at a landscape scale under controlled conditions. This allows for replicated manipulations to provide sound science for the Comprehensive Everglades Restoration Plan (CERP), a multi-agency effort to maintain and restore the Everglades ecosystem. LILA is located at the Arthur R. Marshall Loxahatchee National Wildlife Refuge, Boynton Beach, Florida (N26º29.600’, W80º13.000’) and spans just over 34 ha (Figure 1). LILA consists of four macrocosms, which mimic the Everglades ridge-and-slough and tree island topography, each with an area of 8 ha. Each macrocosm contains two tree islands (with differing cores, either peat or limestone), shallow and deep sloughs and one large ridge. The goal of LILA is to provide a research facility that allows the study of the responses of wildlife, tree islands and ridge-and slough communities to changes in surface water level and flow. The studies at LILA are designed to increase understanding of the dynamics of the tree islands and the effectiveness of Everglades restoration techniques by providing high-resolution data with multiple replicates in a hydrologically controlled area (Gawlik et al. 2003).

The climate of the region is characterized by distinct wet (mid-May through October) and dry (November to mid-May) seasons with an average annual precipitation of 120 cm over the last ten years. During the wet season, precipitation can be described as bimodal, with the highest precipitation occurring in June and August. The surface water levels in LILA are controlled to mimic those of the Everglades, with the highest surface water levels from September to January, flooding the tree islands, and the lowest surface water levels from April to June (Figure 2). In this study, the wet and dry season are designated when surface water levels are high or when surface water levels are low. Two of the four macrocosms maintain an average surface water flow of 1-2 cm s^{-1} while the other two macrocosms maintain low to no surface water flow. The average annual temperature in the area is 23.5°C with maximum temperatures reaching 36°C in the summer and minimum temperatures reaching 2°C for short periods in the winter.

In the spring and fall of 2006, nine wells were augured or drilled into each of the tree islands. The wells on each of the eight tree islands at LILA have an average depth of 1.34±0.15 m and an average bottom elevation of 3.49 ±0.08 m (NGVD-29). In April 2008, one deeper well was installed on each of the peat islands, with an average depth of 1.83±0.02 m. The four deeper wells were located within the high density tree planting quadrants near the center of the island. Each well has a diameter of 3.8 cm and a screen interval of 0.6 m or 0.43 m at the bottom. In August 2008, an additional twelve wells were installed on the eastern sides of the four macrocosms. Three wells were installed in each macrocosm; two in the slough, one adjacent to the tree island and one adjacent to the ridge, and one in the center of the ridge. The average depth of wells in the sloughs is 1 m, while the average depth of wells in the ridges is 1.07 m. The wells on each tree island and the surface water sites (GW/SW samples) are numbered according to the following convention: each GW/SW sample name begins with the letter M and a number 1 through 4. This designation corresponds to macrocosms 1 through 4, which are located from north to south in LILA (Figure 1). The next letter of the GW/SW sample name corresponds to the locations of the tree islands in each macrocosm. Islands located to the east are designated with the letter E while those to the west are represented with the letter W (Figure 1). Surface water sites are then designated with the letter b indicating they occur on the boardwalk. The groundwater wells are further distinguished by a number from 1 through 12, numbers 1-9 refers to the placement of the well on the tree island, while 10-12 refers to the placement of the wells on the slough and ridge. Well #1 is always located on the southwest side of the island while well #9 is always located on the northeast side of the island (Figure 3). The four deeper wells and the twelve ridge and slough wells have a lower case that follows the well number, d for the deep wells, s for the slough wells and r for the ridge wells (Figure 4). The last letter of the well designation corresponds to the type of geologic material underlying the tree islands. The letter P refers to peat while L corresponds to limestone rumble. M4W8dP would be an example of the well numbering system and would be designated as the deep well in 8th well location in macrocosm 4 on the west peat core tree island.

Each of the tree islands were planted in four planting densities, with the trees spaced 1, 1.66, 2.33 and 3 m apart (Figure 1). The four density treatments or quadrants were randomly assigned to four 24 x 16 m quadrants on each island. Eight of ten species common to the Everglades were planted on each island for a total of 89 trees of each species on each tree island. Tree islands in M1 and M4 were planted in February 2006, while the tree islands in M2 andM3 were planted in February 2007. One well is located in each density tree-planting while five other wells are located between the quadrants.

IV. Methods

To determine how nutrient availability in tree islands varied with seasonal hydrodynamics, underlying geology and within the ridge-slough-tree island continuum at LILA, four groundwater wells were sampled on each of the four limestone based islands and five groundwater wells were sampled on each of the four peat based islands in October of 2008. The additional well on the peat based islands was the deep well. To compare findings from the tree islands to the ridge and slough areas, one well in the ridge and one well in the slough was sampled per macrocosm. In addition, the surface water was sampled from each island's respective boardwalk for a total of forty-two groundwater samples, and eight surface water samples collected in October 2008 (Figure 4). To determine the effect of differing evapotranspiration rates, wells were sampled across a low to high density tree-planting transect (Price and Sullivan 2008). Groundwater was sampled from wells located in the 1 m and 3 m tree spacing quadrants. In addition, wells located between the two planting quadrants and in the center of the island were sampled to gain a better understanding of the spatial variability across the islands. The location of these density quadrants differed across each island from north to south and east to west but the distance of the wells from the edge of the islands remained relatively the same.

All wells and surface water sites were sampled using a peristaltic pump and each well was purged of three well volumes before sampling. Temperature, conductivity, dissolved oyxgen and pH were measured in the field using an Orion multi-probe (relative accuracy of ±0.1°C and ±0.1 μS/cm), a YSI 85 probe (relative accuracy of ±0.1°C, ±0.1 μS/cm and ±0.03 mg/L) and a Thermo three-start pH meter (relative accuracy of ±0.002). Five samples were collected per well, three filtered and two unfiltered. One filtered and one unfiltered nutrient sample were preserved with 10% HCl. Six samples were collected at each surface water location with three filtered and three unfiltered samples collected using the South Florida Water Management District (SFWMD) protocol for nutrient preservation by nitric and sulfuric acids. All samples were stored at 4ºC, surface water nutrient samples were transported to SFWMD while all other samples were transported to Florida International University. Groundwater and surface water samples were analyzed for alkalinity, anions, cations, oxygen and hydrogen isotopes at FIU's Earth Sciences HydroLab using a Brinkman Titrino 751/735 automated titration unit, Dionex-120 Ion Chromatograph and a DTL-100 Liquid-Water Isotope Analyzer, respectively. Dissolved nutrients, total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) were analyzed by the NELAC certified Southeastern Environmental Research Center (SERC) nutrient analysis laboratory.

Soil water and stem water were also sampled and analyzed for the stable isotopes of oxygen and hydrogen to gain a better understanding of plant-water interactions. Three species of trees were sampled; *Chrysobalanus iaco* (*CI*), *Annona glabra* (*AG*) and *Myrica cerifera* (*MC*). When available, three of each of these species were sampled from four different areas on each island: high-elevation high-density; high-elevation low-density; low-elevation high-density; and low-elevation low-density. High density quadrants were those with 1 m spacing between trees while the low density quadrates were those with 3 m and 2.66 m spacing between the tree. Six of the eight tree islands were sampled for stem water with a total of 136 samples collected in October 2008, and 197 in May of 2009. In October 2008, a total of 8 soil water samples were collected by sampling soil at a depth of 14 cm. In May of 2009, a total 54 soil water samples were collected at depths of 10 cm and 20 cm. All samples were cryogenically distilled at the University of Miami, Stable Isotope Ecology Lab. Once water was extracted, the oxygen and hydrogen isotopes were run at FIU.

To check the accuracy of the major dissolved constituent values in the surface water, a charge balance error was performed. A charge-balance error was calculated as the sum of all of the major cations (meq/L) minus the sum of all of the major anions (meq/L) divided by the sum of the cations and anions in (meq/L) multiplied by 100 to report the error as a percentage. A charge balance error of less than 10% indicated that all of the major cations and anions had been measured with confidence. Linear regressions (α=0.05) were used to determine significant correlations between chemical constituents in the groundwater. Two-tailed T-tests with an $\alpha = 0.1$ were used to compare groundwater chemistry between planting years (Planting-1 and Planting-2). An ANOVA (α=0.1) and a post-hoc Tukey test were used to determine if there were any significant differences in the groundwater chemistry between ridge, slough, and tree islands communities. In addition, an ANOVA was also used to determine if the groundwater chemistry significantly differed across the variable tree density transects, where all wells were grouped into three categories; 1) wells located in the high density tree-plantings (high); 2) wells located in low density tree-plantings (low); and 3) wells located between the tree-planting quadrants (center).

V. Results

i. Field Parameters

The field parameter data was grouped according to the wet and dry season. The average surface water parameters were compared to the average of the groundwater parameters (Table 1 and 2). The groundwater well data was then broken down into four groups; tree islands, deep, slough and ridge. The groundwater from the tree islands includes all of the wells except the four deep wells on the tree islands. The deep wells were placed in their own group.

a. Wet Season

The groundwater temperature was slightly cooler than the surface water and averaged 27.1±0.6 °C and 27.3±0.5 °C, respectively (Table 1 and 2). In addition, the pH of the groundwater was significantly lower than the surface water with an average of 6.54 and 7.61, respectively. The average pH was calculated as the inverse log of the average log pH (or hydrogen ion activity). The dissolved oxygen concentration was also higher in the surface water as compared to the groundwater with an average of 2.36 mg L^{-1} and 0.10 mg L^{-1}, respectively. Conversely, the conductivity was significantly higher in the groundwater, with an average value of 993 $\mu S\ cm^{-1}$, as compared to the surface water that averaged 347 $\mu S\ cm^{-1}$ (Table 1 and 2).

The warmest groundwater temperatures were detected in the slough with an average of 27.3 °C, while the coolest temperatures were detected in the deep wells with an average of 26.6 °C. The groundwater temperatures in the ridges and tree islands were similar and averaged 26.9 °C and 27.0 °C, respectively. The average pH of the groundwater from the deep wells and sloughs were very similar, with average values of 6.80 and 6.78. The pH of the groundwater from tree islands and ridges were lower compared to the sloughs and deep wells, with average values of 6.34 and 6.52, respectively. The dissolved oxygen concentration from all locations was very similar and averaged 0.10 mg L^{-1}. The conductivity of the groundwater was highest in the tree islands and continued to decrease from the slough to the ridge, with average values of 1119 μS cm^{-1}, 681 μS cm^{-1} and 514 μS cm^{-1}, respectively. The groundwater conductivity in the deep well was higher than that of the slough or ridge but lower than the tree islands with an average value of 1025 μS cm^{-1} (Table 1 and 2).

b. Dry Season

Similar to the wet season, the average groundwater temperature in the dry season was slightly cooler that the surface water, with an average of 24.0 ± 0.7 °C and 24.3 ± 0.67 °C, respectively (Table 1 and 2). The pH of the surface and groundwater during the dry season were elevated as compared to the wet season, with an average of 7.77 and 6.64, respectively. The dissolved oxygen concentrations were relatively similar to the wet season with an average of 0.65 mg L^{-1} in the groundwater and 2.23 mg L^{-1} in the surface water. The average surface water conductivity was 106 μS cm^{-1} higher in the dry season, with an average of 453 μS cm^{-1}. Conversely, the groundwater conductivity averaged 142 μS cm^{-1} lower in the dry season, with an average of 851 μS cm^{-1}.

The groundwater temperatures in the sloughs were substantially warmer than the groundwater from the ridges, tree islands or deep wells, and averaged of 25.1 °C. The groundwater temperatures in the deep wells were the coolest with an average of 23.5 °C. Groundwater temperatures in the ridges and tree islands were lowest and averaged 23.8 °C and 23.9 °C, respectively.

ii. Analytical Results

The analytical results are presented in units of milligrams per liter (mg L^{-1}) and micrograms per liter (μg L^{-1}). The following are the results of the chemical constituents measured in the groundwater and surface water (Table 3, 4 and 5). The groundwater results are further grouped according to areas within the macrocosm (tree islands, deep wells, sloughs and ridges) and then within the tree islands (high density, center, and low density).

a. Ridge-Slough-Tree Islands-Deep Groundwaters

The average groundwater concentrations of most chemical constituents were lowest in the ridges and highest in the tree islands for both the wet and dry sampling events. During the wet season, the average groundwater concentrations of total alkalinity and chloride were elevated in the tree islands as compared to the deep wells, ridges and sloughs, with values of 655.47 mg L^{-1} HCO_3^- and 42.21 mg L^{-1} in the tree islands, 573.79 mg L^{-1} HCO_3^- and 35.76 mg L^{-1} in the deep wells, 432.81 mg L^{-1} HCO_3^- and 25.23 mg L^{-1} in the slough, and 277.07 mg L^{-1} HCO_3^- and 29.54 mg L^{-1}(Table 3 and 6**,** Figure 5) Unlike the other anions, the groundwater concentration of sulfate was highest in the tree islands and sloughs compared to the deep wells and ridges, with values of 0.78 mg L^{-1}, 0.35 mg L^{-1}, 0.03 mg L^{-1}, and 0.05 mg L^{-1} (Table 3 and 6). The average concentrations of the cations followed a similar pattern with the highest concentrations detected on the tree islands and the lowest values detected in the ridges (Figure 5). In most instances the average concentration of the tree island groundwater was very similar to that of the deep groundwater, with values for sodium, potassium, magnesium and calcium at 33.37 and 30.87 mg L^{-1}, 6.45 and 6.67 mg L^{-1}, 14.69 and 12.96 mg L^{-1}, and 176.74 and 161.67 mg L^{-1}, respectively (Table 3 and 6**,** Figure 5 and 6). The average potassium concentrations did not hold true to the general pattern, instead the highest concentrations were detected in the sloughs, with an average value of 10.30 mg L^{-1}, while the lowest average concentration was detected in the ridges, with a value of 2.99 mg L^{-1}. Though in all cases the groundwater concentrations in the ridges were the lowest, the concentration of calcium in the ridge groundwater was substantially lower than on the tree islands with an average value 82.86 mg L^{-1}. Only one of the 44 groundwater samples taken during this period had a charge balance error greater than 10%, the error was detected in well M3E5P (Table 3). The average concentration of Nitrite+Nitrate was highest in the deep groundwater with a value of 11.03μg L^{-1}. The groundwater concentrations in the ridges, sloughs and tree islands were similar and had an average value of 7.40 μg L^{-1} (Table 4 and 6, Figure 6). Concentrations of ammonium, total phosphorus, soluble reactive phosphorus and total organic carbon were all highest in the tree islands with average values of 6.28 mg L^{-1}, 123.97 μg L^{-1}, 52.14 μg L^{-1}, and 42.23 mg L^{-1} (Table 4 and 6, Figure 6 and 7). In the cases of ammonium and total phosphorus, the concentrations in the deep groundwater and the sloughs were very similar, with average values of 3.69 and 3.50 mg L^{-1}, and 42.55 and 48.82 μg L^{-1}, respectively. The lowest concentrations of soluble reactive phosphorus and total organic carbon were detected in the deep groundwater with average concentrations of 12.76 μg L^{-1} and 27.22 mg L^{-1} (Table 4 and 6 Figure 7).

In the dry season, the average concentration of alkalinity in the groundwater decreased in all instances except for the groundwater in the ridges, with the average concentrations in the tree islands, deep wells, sloughs and ridges being 546.06, 564.42, 377.63 and 339.13 mg L^{-1} HCO_3^-, respectively (Table 3 and 6**,** Figure 5). Conversely, the average groundwater chloride concentrations increased by at least 1-2 mg L^{-1}, with the largest increase of 8 mg L^{-1} occurring in the deep wells. Similar to the wet season, the groundwater concentration of sulfate was low at all locations, with the highest concentration of 0.06 mg L^{-1} detected in the sloughs (Table 3 and 6). In almost all instances, the groundwater concentrations of cations decreased slightly or remained the same from the wet to the dry season. The only exceptions were an increase in calcium in the deep groundwater and an increase in magnesium in the ridge groundwater (Figure 5 and 6). Three of the 44 groundwater samples taken during this period had a charge balance error greater than 10%, these wells were M2E12R, M2E5P and M4E12R (Table 3). Concentrations of Nitrate+Nitrite slightly decreased in the ridge and slough groundwater but increased in the tree islands and deep groundwater, with average values of 5.44, 5.85, 10.82 and 32.32 μg L^{-1}, respectively (Table 4 and 6 and Figure 6).

Concentrations of ammonium, total phosphorus, soluble reactive phosphorus and total organic carbon all decreased from the wet to the dry season with the ridge, slough and deep groundwater having similar concentrations and the concentrations in the tree island groundwater being substantially higher (Table 4 and 6, Figure 6 and 7).

b. Variable Tree Densities Within the Islands

Within the tree islands, the low density tree planting quadrants tended to have the lowest groundwater concentrations of the chemical constituents measured as compared to the center of the tree islands and high density tree planting quadrants in both the wet and dry season. During the wet season, the values at the center of the tree islands and within the high density tree planting quadrants tended to be similar. This pattern held true for groundwater concentrations of alkalinity with values of 574.37, 682.71 and 685.51 mg L^{-1} HCO_3^- for the low density, center and high density tree planting quadrants, respectively (Table 3 and 7, Figure 8). Concentrations of chloride and sulfate were elevated in the center of the tree islands as compared to both the high and low density tree planting quadrants, with values of 48. 28 mg L^{-1} compared to 39.65 and 34.41 mg L^{-1}, and 1.49 mg L^{-1} compared to 0.04 and 0.03 mg L^{-1}, respectively (Table 3 and 7, Figure 8). The groundwater concentrations of sodium, potassium, magnesium, and calcium followed the dominant trend, with the lowest values detected in low density tree planting quadrants as compared to the center and high density tree planting quadrants which had similar values. The values of sodium, magnesium and calcium were only slightly lower in the low density tree planting quadrants as compare to the center and high density areas, with the average values of 28.39, 35.59, and 32.42 mg L^{-1} for sodium, 12.51, 15.57 and 15.08 for magnesium, and 160.09, 184.84 and 10.45 mg $L^{-1}$for calcium, respectively (Table 3 and 7, Figures 8 and 9). The low density tree planting quadrants had half the concentration of potassium as compared to the center and high density tree planting quadrants. Unlike all other chemical constituents, the concentration of nitrate+nitrite was highest in the low density tree planting quadrants and lowest in the center of the tree islands with values 9.26 and 7.97 μg L^{-1}, respectively (Table 4 and 7, Figure 9). The average concentrations of ammonium, total phosphorus, and soluble reactive phosphorus were similar in the center of the tree islands and high density tree planting quadrants with values of 7.06 and 6.58 mg L^{-1}, 136.97 and 147.57 μg L^{-1}, and 62.71 and 57.25 μg L^{-1} (Table 4 and 7, Figure 9 and 10). In the low density tree planting quadrants, the average concentration of total phosphorus and soluble reactive phosphorus were two thirds lower than those from the center and high density tree planting quadrants, with values of 48.71 μg L^{-1} and 15.53 μg L^{-1}, respectively (Table 4 and 7, Figure 9 and 10). The average values of total organic carbon were elevated in the center of the tree islands as compared to the high and low density tree planting quadrants.

In most instances, the patterns of the average concentration remained the same from the wet to the dry season, though the values of most of the chemical constituents decreased. The groundwater concentration of alkalinity decreased approximately 100 mg L^{-1} HCO_3^- for the low, center and high density tree planting quadrants (Table 3 and 7, Figure 8). The average chloride concentrations increased in both the high and low density tree planting quadrants with values of 46.44 and 40.38 mg L^{-1}, respectively, while values in the center of the tree islands decreased in the dry season (Table 3 and 7, Figure 8). Concentrations of sulfate, sodium, potassium, magnesium and calcium had all decreased in the dry season. The values of sodium and magnesium were similar across the low to high density transect with 5 mg L^{-1} separating the highest and lowest average sodium concentrations, and 2 mg L^{-1} separating the highest and lowest average magnesium concentrations (Table 3 and 7, Figure 8 and 9). The average concentrations of calcium decreased by an average of 35 mg L^{-1} in the dry season, with the highest values detected in the center of the tree islands. Opposite from the wet season, the concentrations of nitrate+nitrite were highest in the center of the tree islands and lowest in the low density tree planting quadrants, with average values of 13.76 and 6.62 μg L^{-1} (Table 4 and 7, Figure 9). Values of ammonium, total phosphorus and soluble reactive phosphorus decreased from the wet to the dry season. In all instances the concentrations of these three constituents were lowest in the low density tree planting quadrants, with average concentrations of 2.78 mg L^{-1}, 23.93 μg L^{-1}, and 5.05 μg L^{-1}, respectively (Table 4 and 7, Figures 9 and 10). The concentrations of ammonium were similar in the center and high density tree planting quadrants, with average values of 4.17 and 4.49 mg L^{-1}, respectively. Similar to the wet season, the highest average concentration of total phosphorus (118.45 μg L^{-1}) was detected in the high density tree planting quadrants, while the highest average concentration of soluble reactive phosphorus (19.61 μg L^{-1}) was detected in the center of the tree islands (Table 4 and 7, Figure 10). In both instances there was an average decrease of at least 30 μg L^{-1} from the wet to the dry season in the center and high density tree planting quadrants. The concentration of total organic carbon was similar from the wet to the dry season, with about 5 mg L^{-1} separating the highest average concentration (center of the islands) and the lowest average concentrations (high density tree planting quadrants) (Table 4 and 7, Figure 10).

c. Surface Water

In general, the average concentrations of the chemical constituents monitored in the surface water were substantially lower than the groundwater in the tree islands. From the wet to the dry season there was an overall increase in the ionic strength of the surface water. The average surface water concentrations of alkalinity, chloride, sodium, potassium, magnesium and calcium increased by 7.01mg L^{-1}, 29.77 mg L^{-1}, 19.61 mg L^{-1}, 3.95 mg L^{-1}, 3.48 mg L^{-1}, and 5.27 mg L^{-1}, respectively (Table 5). The average concentrations of chloride and sodium in the surface water during the dry season were elevated as compared to the groundwater. Of the 16 surface water samples collected in these two sampling events only one sample had a charge balance error greater than 10% (Table 5). Surface water concentrations of ammonium and total phosphorus were also slightly elevated in the wet season as compared to the dry season, with values increasing from 0.10 to 0.11 mg L^{-1} and 8.29 to 11.38 μg L^{-1}, respectively. The concentrations of soluble reactive phosphorus were below the limit of detection (2 μg L^{-1}) in the wet and dry season.

iii. Groundwater and Surface Water Stable Isotopes

The average oxygen and hydrogen isotopic composition of the surface water during the wet season (δD=2.43‰ and $\delta^{18}O$=0.37‰) was depleted as compared to the dry season (δD=26.02‰ and $\delta^{18}O$=5.05‰). At both periods the surface water was enriched as compared to the groundwater, though during the wet season (δD=1.93‰ and $\delta^{18}O$=0.11‰) the difference was smaller as compared to the dry season (δD=1.78‰ and $\delta^{18}O$= 0.19‰) (Table 4 and 5). The isotopic values of the groundwater are further grouped according to areas within the macrocosm (tree islands, deep wells, sloughs and ridges), then within the tree islands (edge vs. center) and then according to the year they were planted, islands planted in 2006 will be referred to as Planting-1, while those planted in 2007 will be referred to as Planting-2.

a. Ridge-Slough-Tree Islands-Deep Groundwaters

The average isotopic composition of groundwater in the sloughs were always enriched as compared to the groundwater water in ridges, deep groundwater and tree, with values δD=5.26‰ and $\delta^{18}O$=0.98‰ during the wet season and δD=4.95‰ and $\delta^{18}O$=0.83‰ during the dry season (Figure 11). During the wet season the isotopic composition the groundwater in the ridges, deep wells and surface water were similar with average values of δD=4.42‰ and $\delta^{18}O$=0.36‰, δD=2.92‰ and $\delta^{18}O$=0.29‰ and δD=2.43‰ and $\delta^{18}O$=0.37‰, respectively (Table 8, Figure 11). The average isotopic value of the tree island groundwater (δD=1.27‰ and $\delta^{18}O$=-0.08‰) were depleted as compared to all of the other groundwater and was substantially lower than the average isotopic values from ridge and surface water. During the dry season this pattern did not persist, the lowest average isotopic value was detected in the deep groundwater (δD=0.53‰ and $\delta^{18}O$=-0.11‰), and was isotopically similar to the tree island groundwater (δD=1.29‰ and $\delta^{18}O$=0.08‰). The groundwater from the sloughs (δD=4.95‰ and $\delta^{18}O$=0.83‰) and ridges (δD=4.34‰ and $\delta^{18}O$=0.58‰) were also similar and considerably enriched as compared to the groundwater from the tree islands and deep wells (Figure 11, Table 8).

b. Edge vs Center groundwater

Within the tree islands, there was no significant difference between the isotopic values across the low to high density transect but when the wells located on the edge of the tree islands were grouped together and compared to those in the center of the tree islands, distinct difference were detected. During both the wet and dry season, the isotopic signature of the groundwater in the center of the tree islands (δD=-0.29‰ and $\delta^{18}O$=-0.53‰ and δD=-1.72‰ and $\delta^{18}O$=-0.35‰) was significantly (α=0.05) depleted as compared to all other groundwater (Figure 12). During the wet season the groundwater at the edges of the tree islands average δD=2.91‰ and $\delta^{18}O$=0.37‰ and had isotopic values similar to the surface water and deep groundwater. During the dry season the groundwater on the edges of the islands average δD=4.12‰ and $\delta^{18}O$=0.49‰ and was depleted as compared to the surface water but enriched as compared to the deep groundwater (Figure 12).

c. Planting-1 vs Planting-2 groundwater

When the tree islands were compared between planting years, the average isotopic composition of the groundwater in the older tree islands (Planting-1) was always isotopically depleted as compared to the younger tree islands. During the dry season the isotopic value of the groundwater from Planting-2 averaged δD=3.27‰ and $\delta^{18}O$=0.42‰

and was similar to the average isotopic composition of the surface water and the deep groundwater (Figure 13). The average isotopic value of the groundwater from Planting-1 (δD=-0.26‰ and δ^{18}O=-0.47‰) was significantly depleted as compared to the groundwater from Planting-2. During the dry season, the surface water was significantly enriched as compared to all the measures of groundwater, while the groundwater in the deep wells had the most depleted values. Though the isotopic value of the groundwater from Planting-1 (δD=0.88‰ and δ^{18}O=0.07‰) was lower than Planting-2 (δD=2.02‰ and δ^{18}O=0.25‰), the values were not significantly different from each or the deep groundwater (Figure 13).

iv. Soil water and Stem Water Stable Isotopes

The average oxygen and hydrogen isotopic composition of the soil water during the wet season (δD=3.03‰ and δ^{18}O=0.33‰) was depleted as compared to the dry season (δD=6.41‰ and δ^{18}O=1.19‰) (Figure 14). During the wet season all samples were taken from a depth of 14 cm but during the dry season soil water samples were taken from a depth of 10 cm and 20 cm. The average isotopic composition of the soil water at a depth of 20 cm (δD=4.45‰ and δ^{18}O=0.66‰) was significantly (α=0.05) depleted as compared to the soil water composition at 10 cm (δD=8.23‰ and δ^{18}O=1.68‰). In wet and dry season the average stem water compositions were very similar to the soil water with values of δD=2.96‰ and δ^{18}O=0.85‰ and δD=5.25‰ and δ^{18}O=1.01‰, respectively (Table 8, 9 and 10, Figure 14). Two spatial relationships that were detected in the groundwater were also detected in the stem water. First, the average isotopic composition of the stem water in the center of the islands (Wet Season δD=1.25‰ and δ^{18}O=0.52‰ and Dry Season δD=0.74‰ and δ^{18}O=0.37‰) was significantly (α=0.05) depleted as compared to the edges (Wet Season δD=4.90‰ and δ^{18}O=1.22‰, Dry Season δD=10.09‰ and δ^{18}O=1.71 ‰) (Figure 15). In addition, the average isotopic composition of the soil water during the dry season showed the same pattern with values of δD=1.57‰ and δ^{18}O=0.34‰ in the center of the tree islands and δD=10.90‰ and δ^{18}O=1.97‰ at the edge of the islands. During the dry season, the isotopic composition of the soil water and stem water in the center and edges of the islands were significantly enriched as compared to the groundwater (Figure 15). Second, the average isotopic composition of the stem water from the Planting-1 was significantly lower than Planting-2, with values of δD=1.09‰ and δ^{18}O=0.52‰ and δD=5.15‰ and δ^{18}O =1.24‰, respectively (Figure 16). During the dry season, this relationship was not detected in the stem water, soil water or groundwater. When the average isotopic composition of the three species were compared, the most depleted values were detected in the stem water from *Chrysobalanus iaco* (*CI*) (Wet Season δD=0.46‰ and δ^{18}O=0.57‰, Dry Season δD=1.97‰ and δ^{18}O=0.34‰) and the most enriched values detected in *Annona glabra* (*AG*) (Wet Season δD=5.05‰ and δ^{18}O=1.14‰, Dry Season δD=8.66‰ and δ^{18}O=1.62‰) (Figure 17). During the wet season the average isotopic composition of *CI* was similar to the slough groundwater and the soil water, while during the dry season the average isotopic composition of *CI* was similar to the tree island's groundwater and the soil water at a depth of 20 cm (Figure 17). The isotopic composition of *Myrica cerifera* (*MC*) and *AG* was similar to the slough groundwater during the wet season and similar to the soil water at 10 cm during the dry season.

A linear regression between the isotopic composition of the stem water and the respective groundwater indicated that there was a difference between the center of the islands and the edges of the tree islands. If the slope of the linear regressions was equal to one (1) then it can be inferred that the trees were relying solely on groundwater. In the center of the tree islands the slope of the regressions were positive and ranged from 0.5 to 0.9, which suggests the trees were relying partly on groundwater (Figure 18). At the edges of the islands the average stem water and groundwater were uncorrelated during the wet season, and had negative correlation during the dry season, which suggest the trees accessed water from other source. When a linear regression between isotopic composition of the stem water and the respective groundwater for both locations (Edge vs Center) and plantings (Planting-1 vs Planting-2), the center of the tree islands planted in 2006 had a positive slope in the both the wet and dry seasons, while a positive slope was only detected in the center of the islands planted in 2007 during the dry season (Figure 19). The groundwater and stem water were uncorrelated at the edges of the islands and in center of the islands of Planting-2 islands during the wet season.

V. Statistical Results

a. Correlations

A number of significant relationships were detected between the chemical constituents in the groundwater using a correlation matrix with an α=0.01 in both the wet and dry season sampling (Table 11 and Table 12). In the wet season there was a significant positive correlation between ammonium, total phosphorus, total organic carbon and conductivity, alkalinity, sodium, potassium, magnesium, and calcium. In addition, there was a significant positive correlation between all anions and cations except for sulfate. The isotopic composition of the water, δD and $\delta^{18}O$, was significantly correlated to temperature (r^2=0.394 and 0.392, respectively). In addition, a significant negative correlation was detected between the isotopic composition of the groundwater and total alkalinity, chloride, sulfate, total nitrogen and total organic carbon. Furthermore, soluble reactive phosphorus was significantly correlated with ammonium (r^2= 0.631). Many of the same correlations that were detected in the wet season were detected in the dry season. Unlike the wet season, significantly negative correlations were not detected between δD and $\delta^{18}O$ and sulfate and sodium, though a significantly negative correlation was detected between ammonium and δD and $\delta^{18}O$. Similar to the wet season there were a number of significantly positive correlations between cation, anions, total phosphorus and ammonium.

b. Different Plantings

The islands in macrocosms 1 and 4 (Planting-1) were planted in the spring of 2006, while those in macrocosms 2 and 3 (Planting-2) were planted one year later. In this section the chemical constituents of Planting-1 were compared with Planting-2 using two tailed t-tests (α=0.1) (Table 13). During the wet season, Planting-1 had significantly higher concentrations of conductivity, alkalinity, chloride and magnesium as compared to Planting-2 with average difference in concentrations of 173.5 $\mu S\ cm^{-1}$, 123.45 mg L^{-1}, 2.54 mg L^{-1} and 43.18 mg L^{-1}, respectively. During the dry season these significant differences persisted with an average difference in concentrations of 190.6 $\mu S\ cm^{-1}$, 129.11 $mg\ L^{-1}$, 2.32 $mg\ L^{-1}$ and 46.42 $mg\ L^{-1}$, respectively. In addition, the pH of the groundwater was significantly higher in the Planting-1 tree islands as compared to the Planting-2 tree islands.

c. Ridge-Slough-Tree Islands-Deep Groundwaters

Although groundwater from the tree islands generally had higher concentrations of all chemical constituents as compared ridge, slough and deep groundwater, an analysis of variance ($\alpha = 0.1$) indicated significant differences between the groups for conductivity, alkalinity, magnesium and calcium during the wet season (Table 6). Post-Hock Tukey test ($\alpha = 0.1$) revealed that there were significantly lower conductivity values in the ridge groundwater as compared to the tree islands and deep wells, while the concentration of conductivity were significantly lower in the slough as compared to the tree islands groundwater. Furthermore, a Post-Hock Tukey test ($\alpha = 0.1$) revealed that there were significantly lower concentrations of total alkalinity, magnesium and calcium in the ridge groundwater as compared to the tree islands groundwater. The groundwater concentration of magnesium was significantly higher in the tree islands as compared to the sloughs.

An analysis of variance ($\alpha = 0.1$) for the dry season indicated significant difference between the groups for conductivity, alkalinity, chloride magnesium and calcium. Post-Hock Tukey test ($\alpha = 0.1$) revealed significantly lower groundwater values of conductivity and calcium in the ridge as compared to the tree islands and deep wells. In addition, significantly higher groundwater concentrations of chloride, sodium and magnesium in the tree islands as compared to the slough. Significantly higher groundwater concentrations of alkalinity were detected in the tree islands as compared to the ridge.

VI. Discussion

The results of tree island, ridge and slough groundwater chemistry sampling at Loxahatchee Impound Landscape Assessment (LILA) in October 2008 and May 2009 follow many of the same spatial patterns that have been detected in the Everglades. The groundwater concentrations of alkalinity, chloride, total nitrogen, total phosphorus and soluble reactive phosphorus were all lower in the slough as compared to the tree islands. Ross et al. (2006) found concentrations of SRP ranged from 0.7 $\mu g\ L^{-1}$ in the marsh to about 200 $\mu g\ L^{-1}$ at the head of the tree islands in Everglades National Park (ENP). At LILA, the groundwater concentrations of SRP ranged from 9-12 $\mu g\ L^{-1}$ in the sloughs and 65 $\mu g\ L^{-1}$in in the center of the island. Furthermore, Wetzel et al. (2005) reported pore water concentrations of total phosphorus on the heads of two tree islands in Water Conservation Area 3 ranged from 230 to 400 $\mu g\ L^{-1}$ while the pore water in the adjacent marsh had concentrations of less than 10 $\mu g\ L^{-1}$. In addition, he found that chloride concentrations were an order of magnitude higher in heads of tree islands (123 $mg\ L^{-1}$) as compared to the marsh (15.75 $mg\ L^{-1}$). Though the magnitude of difference between sloughs as compared to the tree islands was not as great at LILA, the chemistry of the groundwater in the sloughs was distinct from that of the tree islands.

In addition to differences in the groundwater chemistry between these three landscape features, the groundwater chemistry within the islands varied with overlying tree density and distance from the edge of the islands. The groundwater chemistry in the high density tree planting quadrants and the center of the tree islands had very similar concentrations of alkalinity, total phosphorus and soluble reactive phosphorus, while the concentrations in the low density tree planting quadrants were substantially lower. The high concentrations of total phosphorus and soluble reactive phosphorus occurring in the high density quadrants may be attributed to the fertilized soil transplanted during the planting of the trees. In each of the high density quadrants, 425 trees were planted while in the low density quadrants 54 trees were planted. Therefore, about 8 times more nutrient rich soil was added to the high density quadrants. This may also explain the high concentration detected in the center of the islands, because the wells in the center of the islands sit between the low and high density quadrants. When the groundwater concentration of total phosphorus was compared to the results of October of 2007 and May of 2008, the groundwater concentration remained highest in the high density tree planning quadrant and the center of the islands for all sampling events (Figure 20) (Price and Sullivan 2008). Similarly the average concentration of soluble reactive phosphorous was always highest in the center of the tree islands. This may be attributed to a long period of aerobic conditions, which increases microbial action (Corstanje and Reddy, 2004).

The average isotopic composition of the groundwater from the edges and the center of the tree islands indicate increased groundwater-surface water interactions at the edges of the tree islands as compared to the center of the tree islands. When this data is coupled with isotopic and chloride values of the groundwater in the deep wells, sloughs and ridges, it further suggests increased interactions between the adjacent slough groundwater and tree islands during the wet season (Figure 21). During the wet season, the isotopic values and chloride concentrations of the deep groundwater, tree islands edge, and ridge were very similar. For the groundwater in the center of the tree islands, isotopic values were substantially lower and chloride concentrations were considerably higher. During the dry season, the isotopic composition and chloride concentrations of the groundwater from the deep wells, edges and centers the tree islands clustered together. These data suggest that during the dry season there is increased interaction between the deep and shallow groundwater on the tree islands as compared to the wet season. They also suggest that there is a shift in the driving forces behind groundwater-surface water interactions from the wet to the dry season.

Similar to the groundwater, there was a significant difference between the soil water and stem water from the edge of the islands to the center. The isotopic composition of the groundwater compared to the stem water through a linear regression, suggests that the trees in the center of the islands relied on groundwater while those on the edges of the islands relied more on soil water or slough groundwater. Furthermore, the trees in the center Planting-1 islands prominently relied on groundwater in both wet and dry season, while the trees in the center of Planting-2 islands only relied on groundwater during the dry season. In addition, in the wet season the average isotopic composition of the groundwater in the center of Planting-1 islands was significantly depleted as compared to Planting-2 islands. The same significant difference was detected between the stem water between Planting-1 and Planting-2 islands during the wet season. In the dry season no significant difference was detected in the groundwater or stem water between Planting-1 and Planting-2 islands.

The average oxygen and hydrogen isotopic composition of the groundwater in Planting-1 and Planting-2 suggests that there were shifts in groundwater-surface water interactions in the tree islands during May of 2009. In the previous three sampling events (October 2007, May 2008, and October 2008) the average isotopic value of the groundwater from Planting-1 was significantly depleted as compared to Planting-2 (Figure 22). During these sampling events, isotopic composition of the groundwater from Planting-2 was similar to that of the surface water, while the values from Planting-1 were similar to rainfall. In the May 2009 sampling, the isotopic values of Planting-1 were slightly more enriched while those of Planting-2 were slightly more depleted. This suggests that islands may be incurring similar types of groundwater-surface water interactions at this time. This was further supported by the isotopic composition of the stem water. Groundwater level data from the tree islands at LILA suggest there was a shift in groundwater-surface water interactions in September 2008 (Price and Sullivan 2009). The dominate direction of groundwater flow was from the center of the tree islands out toward the sloughs from July 2007 through August 2008. From September 2008 onward, a cone of depression developed in the center of the islands, creating a hydraulic divide on either side of the edges of the islands. This divide caused groundwater to flow from the edge of the islands toward the center and from the edges of the islands toward the slough. In addition, in May 2009, the chloride concentrations in the center of the tree islands were considerably lower than in the three previous sampling events, and had values that were almost the same as the high and low density plots, which may also indicate a shift in groundwater-surface water interactions (Figure 20). During this time (September 2008-September 2009) the above ground biomass on the Planting-1islands increased from 1.82 to 3.13 (t ha^{-1}), while on Planting-2 islands from 1.18 to 1.82 (t ha^{-1}) (Ross and Stoffella, personal communication 2009).

VII. Conclusions

The groundwater and surface water chemistry indicates increased groundwater-surface water interactions on the edges of the islands as compared to the center. The stem water data from the trees suggested that the trees on the edge of the islands relied on soil water or slough groundwater through-out the year, while the trees in the center of the islands relied more on groundwater. Together the data indicated that the groundwater chemistry and groundwater-surface water interactions were driven by plant-water interactions. As the trees grew on the tree islands, the ones in the center and in the high density quadrants relied more on groundwater. Over time, the shallow groundwater in the center of the tree islands became isolated from the surface water and was recharged mainly by rainfall. The groundwater in the tree islands had the highest concentrations of ions and nutrients compared to the ridge and slough areas. These higher concentrations of ions and nutrients were most likely due to a number of processes including but not limited to, evaporation of shallow groundwater, exclusion of ions by transpiration processes, and excess fertilizer applied to the tree islands during the tree planting.

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X. Tables and Figures

Table 1. Groundwater field parameters, temperature (Temp) (°C), conductivity (µS cm^{-1}), pH and dissolved oxygen (DO) (mg L^{-1}). Missing samples are represented by the symbol *.

Site	Date	Temp(ºC)	Conductivity (uS/cm)	pH	DO (mg/L)
M1E10S	10/15/08	27.0	831	7.40	0.11
	5/4/09	24.9	698	6.98	*
M1E12R	10/15/08	27.1	664	6.47	0.06
	5/4/09	24.2	566	6.62	*
M1E3L	10/15/08	27.0	1087	6.46	<0.03
	5/4/09	24.9	1055	6.82	0.09
M1E5L	10/15/08	26.8	1307	6.66	1.24
	5/4/09	24.1	1111	6.86	*
M1E6L	10/15/08	26.3	1089	6.27	0.10
	5/4/09	23.6	924	6.56	1.76
M1E9L	10/15/08	25.9	1079	6.55	0.30
	5/4/09	23.5	957	7.04	1.18
M1W5P	10/15/08	26.7	1296	6.55	0.01
	5/4/09	24.8	1023	6.55	0.41
M1W7P	10/15/08	27.5	1114	6.54	0.06
	5/4/09	23.9	934	7.00	0.56
M1W8dP	10/15/08	26.0	916	6.68	0.04
	5/4/09	23.1	790	6.71	<0.03
M1W8P	10/15/08	26.4	987	6.52	0.05
	5/4/09	24.6	841	6.87	1.03
M1W9P	10/15/08	27.3	1004	6.52	0.21
	5/4/09	23.5	789	6.52	<0.03
M2E10S	10/15/08	27.8	746	*	0.04
	5/4/09	25.0	668	6.74	*
M2E12R	10/15/08	27.1	560	*	0.04
	5/4/09	23.5	517	6.45	*
M2E1P	10/15/08	27.9	821	*	<0.03
	5/4/09	23.5	563	6.28	*
M2E2dP	10/15/08	27.0	743	*	<0.03
	5/4/09	23.4	693	6.55	*
M2E2P	10/15/08	27.4	668	*	<0.03
	5/4/09	23.7	656	6.40	*
M2E3P	10/15/08	27.6	675	*	<0.03
	5/4/09	24.0	582	6.41	*
M2E5P	10/15/08	27.0	720	*	0.10
	5/4/09	23.9	620	6.30	*
M2W5L	10/15/08	27.1	950	*	<0.03
	5/4/09	23.8	822	6.69	*
M2W7L	10/15/08	27.3	792	6.45	<0.03
	5/4/09	23.4	618	6.42	*
M2W8L	10/15/08	27.6	907	6.66	<0.03
	5/4/09	23.7	693	6.71	*
M2W9L	10/15/08	27.7	947	6.44	0.08
	5/4/09	23.5	667	6.50	*

Site	Date	Temp(ºC)	Conductivity (uS/cm)	pH	DO (mg/L)
M3E10S	10/17/08	27.0	854	6.91	*
	5/4/09	24.3	805	7.17	*
M3E12R	10/17/08	26.6	581	7.43	*
	5/4/09	24.0	578	6.91	*
M3E3P	10/17/08	27.4	1226	6.50	<0.03
	5/4/09	24.2	1001	6.70	0.13
M3E5P	10/17/08	27.3	1877	6.74	0.10
	5/4/09	24.5	919	6.70	*
M3E7P	10/17/08	27.0	1352	6.69	<0.03
	5/4/09	24.4	1142	6.63	*
M3E8dP	10/17/08	27.0	1288	6.83	*
	5/4/09	24.1	1157	6.60	*
M3W3L	10/17/08	27.8	1347	6.47	<0.03
	5/4/09	23.8	1083	6.94	0.26
M3W5L	10/17/08	27.3	1104	6.51	<0.03
	5/4/09	24.4	967	6.70	<0.03
M3W6L	10/17/08	27.9	886	6.41	<0.03
	5/4/09	24.0	807	6.60	0.09
M3W9L	10/17/08	27.4	1212	6.51	<0.03
	5/4/09	25.0	914	6.70	0.63
M4E10S	10/17/08	26.7	560	6.55	0.27
	5/4/09	26.2	400	6.86	0.08
M4E12R	10/17/08	27.0	252	6.00	0.19
	5/4/09	23.5	400	6.18	0.28
M4E1L	10/17/08	27.3	912	6.42	<0.03
	5/4/09	23.2	745	6.85	0.37
M4E2L	10/17/08	26.1	1600	6.70	0.14
	5/4/09	23.7	1017	6.89	1.96
M4E3L	10/17/08	27.3	1684	6.43	0.21
	5/4/09	25.0	1483	6.70	1.92
M4E5L	10/17/08	26.2	1461	6.52	0.35
	5/4/09	24.0	1147	6.58	1.66
M4W5P	10/17/08	26.4	1277	6.45	<0.03
	5/4/09	23.5	1171	6.83	*
M4W7P	10/17/08	27.4	1121	6.56	0.08
	5/4/09	23.1	930	6.59	*
M4W8dP	10/17/08	26.4	1153	6.91	0.18
	5/4/09	23.4	1060	6.64	*
M4W8P	10/17/08	26.8	1485	6.47	<0.03
	5/4/09	23.5	1199	6.64	*
M4W9P	10/17/08	27.7	1097	6.34	0.12
	5/4/09	22.8	976	6.85	*

Table 2. Surface water field parameters, temperature (Temp) (°C), conductivity (μS cm^{-1}), pH and dissolved oxygen (DO) (mg L^{-1}).

Site	Date	Temp (ºC)	Cond (uS/cm)	pH	DO (mg/L)
M1Eb	10/13/08	26.6	372.2	7.39	0.51
M1Wb	10/13/08	26.9	361.3	7.5	1.27
M2Eb	10/13/08	27.3	345.2	7.66	3.13
M2Wb	10/13/08	27.1	337.0	7.62	2.16
M3Eb	10/13/08	27.5	326.0	7.55	3.09
M3Wb	10/13/08	27.4	331.6	7.82	3.29
M4Eb	10/13/08	27.8	350.6	7.78	2.84
M4Wb	10/13/08	28.0	350.7	7.76	2.59
M1Eb	5/4/09	23.6	493.0	7.61	0.15
M1Wb	5/4/09	24.1	490.0	7.6	0.32
M2Eb	5/4/09	24.7	443.1	7.99	5.46
M2Wb	5/4/09	23.6	457.4	7.98	3.35
M3Eb	5/4/09	24.2	417.5	7.74	1.15
M3Wb	5/4/09	24.5	429.5	7.76	2.97
M4Eb	5/4/09	25.5	456.5	7.83	3.11
M4Wb	5/4/09	24.4	439.0	7.86	1.36

Table 3. Data from all groundwater samples. The chemical constituents from left to right are: Alkalinity, Chloride (Cl^-), Sulfate (SO_4^{2-}), Sodium (Na^+), Potassium (K^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Ammonium (NH_4^+), Charge Balance Error (CBE).

Site	Alkalinity (mg/L as HCO_3^-)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	NH_4^+ (mg/L)	CBE
M1E10S	536.30	25.89	1.14	23.37	4.16	8.61	150.22	1.27	0.00
	422.01	29.14	0.17	20.23	4.05	9.71	123.67	2.95	0.02
M1E12R	329.47	31.98	0.03	22.66	2.92	10.68	92.80	3.48	0.04
	287.37	30.00	0.00	24.26	2.87	9.37	76.09	3.67	0.03
M1E3L	630.11	41.65	0.05	33.94	5.45	16.16	175.33	6.87	0.02
	666.06	50.87	0.03	32.09	5.29	17.30	187.04	6.27	0.01
M1E5L	751.68	52.25	0.05	34.33	9.70	18.06	191.83	14.04	-0.01
	661.38	43.94	0.02	27.18	6.43	17.30	185.44	2.54	0.00
M1E6L	562.84	53.52	0.04	36.12	8.03	18.16	142.66	19.01	0.03
	538.34	39.86	0.02	21.34	1.80	11.53	144.17	7.67	-0.02
M1E9L	582.37	30.57	0.03	24.17	2.94	12.42	166.46	3.90	0.01
	615.21	35.49	0.01	23.04	3.38	16.41	170.93	3.96	0.00
M1W5P	699.21	58.59	3.14	32.40	4.36	15.95	211.14	5.64	0.01
	615.42	55.42	0.01	29.63	3.42	15.16	180.83	4.93	0.01
M1W7P	685.17	34.66	0.02	26.23	3.84	13.33	183.60	4.09	-0.02
	592.84	33.89	0.00	23.70	2.79	10.16	189.31	1.81	0.04
M1W8dP	527.46	32.85	0.00	23.20	4.12	11.80	149.36	2.98	0.01
	535.08	32.39	0.02	22.37	3.80	11.69	150.31	2.17	0.00
M1W8P	571.08	37.49	0.00	24.88	4.70	12.89	162.52	4.49	0.01
	531.62	31.14	0.00	22.04	3.96	12.33	157.30	2.98	0.03
M1W9P	586.03	35.59	0.05	25.78	2.64	15.05	138.75	7.09	-0.04
	465.53	38.96	0.02	24.83	0.11	7.51	156.31	<0.01	0.04
M2E10S	410.16	18.49	0.08	19.57	13.07	11.03	109.46	4.38	0.04
	392.92	22.18	0.03	17.72	6.81	10.87	101.50	3.73	0.00
M2E12R	274.86	25.42	0.03	18.42	2.74	9.98	77.82	0.89	0.04
	410.62	33.39	0.01	22.31	2.64	8.28	82.21	0.70	**-0.12**
M2E1P	413.36	24.95	0.03	23.09	3.46	12.07	110.95	3.53	0.02
	282.29	34.72	0.00	20.39	0.79	11.74	88.54	0.93	0.06
M2E2dP	430.29	21.72	0.02	24.09	4.71	12.43	113.71	1.17	0.02
	411.63	26.00	0.00	23.22	4.38	12.68	113.26	1.55	0.03
M2E2P	368.97	23.97	0.04	20.59	4.38	11.25	92.81	3.74	0.00
	368.72	32.64	0.00	23.16	3.79	12.87	98.65	3.47	0.02
M2E3P	353.57	22.69	0.02	24.61	1.94	9.59	97.47	0.90	0.03
	279.03	33.26	0.00	25.10	2.50	9.53	76.98	2.17	0.03
M2E5P	324.59	38.27	0.76	34.73	7.48	9.66	86.27	9.44	0.06
	530.00	35.38	0.14	28.34	4.17	8.93	98.02	2.85	**-0.15**
M2W5L	537.07	33.60	0.04	28.64	7.95	13.98	154.62	5.09	0.04
	628.23	33.35	0.00	27.22	2.83	10.62	145.36	2.19	-0.07
M2W7L	461.26	16.47	0.04	22.55	1.64	10.06	132.22	1.06	0.03
	380.72	47.99	0.06	23.76	2.50	11.27	107.14	0.95	-0.01
M2W8L	538.13	28.52	0.27	24.46	4.61	10.38	163.32	1.14	0.03
	451.09	21.47	0.00	20.46	3.00	12.81	126.15	1.53	0.02
M2W9L	534.93	25.24	0.03	27.48	2.15	11.61	145.70	3.19	0.01
	427.70	57.60	0.02	22.27	1.36	9.57	117.31	1.70	-0.05

Site	Alkalinity (mg/L as HCO_3^-)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	NH_4^+ (mg/L)
M3E10S	494.97	26.83	0.13	31.72	9.56	9.69	135.61	5.11
	416.31	29.09	0.03	16.19	1.86	3.56	154.12	0.66
M3E12R	328.71	25.51	0.06	23.54	5.43	7.58	106.71	1.53
	311.78	26.13	0.02	19.94	1.91	8.76	105.03	0.38
M3E3P	689.29	46.23	0.03	42.98	4.12	17.42	181.63	7.40
	554.40	46.48	0.01	35.37	2.46	15.00	166.63	7.15
M3E5P	1325.20	75.46	0.06	62.22	16.08	17.90	263.45	9.37
	464.71	52.36	0.32	41.67	10.06	9.85	144.77	8.06
M3E7P	812.39	30.50	0.03	38.07	13.52	16.31	215.48	6.40
	589.79	44.57	0.06	42.42	8.70	11.25	101.28	5.26
M3E8dP	687.77	41.20	0.10	41.90	12.60	13.08	199.12	7.91
	697.58	47.43	0.00	42.68	7.12	9.86	240.29	4.06
M3W3L	796.67	48.05	0.03	44.95	10.73	17.62	209.42	7.03
	649.58	55.46	0.00	43.32	7.46	15.92	183.00	6.16
M3W5L	578.71	52.10	0.03	39.65	11.28	14.33	156.11	8.03
	546.67	57.94	0.00	45.06	10.61	15.09	155.94	5.90
M3W6L	450.73	37.66	0.04	30.60	5.45	11.76	119.75	7.28
	433.19	52.82	0.12	36.40	4.55	10.19	132.92	2.54
M3W9L	602.20	52.24	0.07	37.88	10.27	14.38	167.75	7.16
	494.61	57.37	0.02	35.40	4.60	12.61	142.30	5.81
M4E10S	289.81	29.71	0.05	23.57	14.39	9.00	62.75	3.23
	207.65	31.08	0.04	21.45	9.49	5.30	45.63	2.11
M4E12R	175.26	35.26	0.07	28.22	0.87	5.95	54.12	0.16
	346.76	34.29	0.02	28.25	1.14	8.83	58.92	0.93
M4E1L	529.90	34.23	0.02	27.97	0.86	11.57	148.52	0.26
	298.76	27.41	0.01	18.01	<0.00	5.53	102.95	<0.01
M4E2L	1021.96	58.44	3.73	50.36	2.94	24.37	294.43	3.94
	678.06	42.41	0.03	22.02	3.23	15.26	195.68	4.96
M4E3L	1163.67	59.54	0.06	39.92	18.52	18.52	274.25	18.87
	898.72	57.32	0.04	34.35	17.18	20.02	238.17	14.37
M4E5L	924.80	42.73	15.49	45.81	3.52	16.08	266.13	2.13
	693.51	55.00	0.03	33.37	5.95	18.47	202.24	6.96
M4W5P	701.80	70.41	0.00	34.70	10.79	14.94	211.01	9.19
	674.60	65.63	0.00	32.60	8.94	14.50	203.05	5.95
M4W7P	626.14	42.70	0.02	24.84	3.43	13.56	180.64	2.59
	551.35	37.94	0.00	23.07	2.68	12.12	168.79	1.74
M4W8dP	649.63	47.27	0.00	34.28	5.26	13.44	184.50	2.71
	613.38	67.86	0.02	34.14	4.86	13.09	182.18	2.30
M4W8P	905.28	65.32	0.05	42.74	11.20	22.18	255.99	7.89
	743.14	51.01	0.00	40.10	11.70	20.18	223.00	<0.01
M4W9P	590.60	34.81	0.04	27.64	2.09	13.88	178.75	3.85
	622.74	34.81	0.01	25.21	1.03	14.78	156.14	2.84

Table 4. Data from all groundwater samples. The chemical constituents from left to right are: Nitrate and Nitrite (N+N), Nitrite (NO_3^-), Nitrate (NO_2^-), Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP) and Total Organic Carbon (TOC), Deuterium, and Oxygen-18. Missing samples are represented by the symbol *.

Site	N+N (µg/L)	NO3- (µg/L)	NO2- (µg/L)	TP (µg/L)	SRP (µg/L)	TOC (mg/L)	δD ‰	δO18 ‰
M1E10S	2.69	<0.03	3.05	15.25	0.70	33.42	4.19	1.31
	3.09	0.05	3.05	23.57	4.85	29.32	1.81	0.43
M1E12R	11.51	<0.03	18.08	17.98	15.95	31.94	5.89	0.76
	11.36	<0.03	15.31	20.97	10.57	35.10	3.08	0.70
M1E3L	17.80	6.93	10.87	114.86	105.36	47.13	2.57	-0.49
	8.10	0.79	7.31	22.80	16.86	43.63	2.91	-0.22
M1E5L	0.75	<0.03	1.40	37.20	4.56	31.42	1.72	-0.79
	20.89	9.29	11.60	22.29	16.12	24.43	2.71	-0.06
M1E6L	10.88	<0.03	16.30	260.71	261.67	44.42	0.63	-1.02
	34.56	20.99	13.57	238.27	66.01	41.36	-6.71	-0.78
M1E9L	7.27	4.37	2.89	49.14	0.92	23.14	0.75	0.20
	6.03	3.86	2.16	57.05	0.40	21.45	-1.34	0.02
M1W5P	14.08	2.52	11.56	*	31.23	49.49	-2.87	-1.06
	13.07	5.34	7.73	49.60	8.11	32.72	-1.20	-0.59
M1W7P	1.76	<0.03	2.79	28.52	2.65	25.74	1.95	0.05
	12.12	11.62	0.51	21.70	1.81	22.21	4.79	-0.15
M1W8dP	5.33	<0.03	5.80	18.29	5.09	22.50	4.75	0.97
	2.28	0.14	2.14	12.99	1.67	20.53	5.60	0.73
M1W8P	9.07	1.32	7.75	25.27	5.38	29.63	2.87	0.08
	2.51	1.06	1.45	47.62	0.31	21.88	0.33	-0.08
M1W9P	10.11	1.16	8.95	14.17	0.81	31.76	8.00	1.59
	10.33	3.08	7.25	65.10	2.09	31.58	13.26	2.36
M2E10S	12.14	0.16	11.98	23.25	12.75	38.78	2.42	-0.12
	8.19	0.49	7.70	20.09	10.53	18.11	1.43	0.17
M2E12R	5.43	<0.03	6.94	27.90	18.20	23.76	3.47	0.38
	4.06	<0.03	6.09	28.76	17.88	25.20	5.20	0.64
M2E1P	5.07	<0.03	5.68	77.93	46.69	26.67	1.14	0.06
	6.07	0.79	5.28	27.94	16.71	63.01	-0.12	-0.37
M2E2dP	5.75	<0.03	7.41	15.50	11.26	25.20	2.07	0.64
	9.11	0.68	8.43	12.84	9.19	23.72	-0.69	-0.27
M2E2P	7.82	1.14	6.67	43.71	29.47	34.74	2.01	-0.36
	7.62	2.19	5.43	14.46	12.68	35.58	-5.19	-0.87
M2E3P	7.52	<0.03	10.08	13.30	5.35	30.61	2.56	-0.09
	8.68	<0.03	11.40	15.87	6.51	32.48	4.26	0.53
M2E5P	6.46	0.81	5.65	123.07	77.22	69.93	1.08	-0.58
	6.24	0.33	5.91	22.93	48.42	63.13	1.42	-0.47
M2W5L	6.33	<0.03	7.33	13.33	7.00	34.82	1.62	-0.08
	21.86	3.98	17.88	16.43	5.44	37.22	0.28	0.38
M2W7L	2.62	<0.03	4.37	29.76	19.74	31.84	2.25	0.31
	3.01	<0.03	5.15	17.29	6.66	38.53	3.52	-0.07
M2W8L	3.32	0.92	2.40	17.67	7.67	39.56	3.39	0.18
	1.86	<0.03	2.42	16.71	4.09	24.91	0.60	0.22
M2W9L	4.54	<0.03	5.95	52.62	26.86	38.44	4.50	0.87
	8.91	<0.03	8.94	12.32	10.23	27.27	0.61	0.61

Site	N+N (µg/L)	NO3- (µg/L)	NO2- (µg/L)	TP (µg/L)	SRP (µg/L)	TOC (mg/L)	δD ‰	δO18 ‰
M3E10S	3.74	<0.03	4.30	114.30	6.43	35.96	7.39	1.23
	6.16	1.49	4.67	25.85	5.10	36.70	7.24	1.31
M3E12R	3.96	0.13	3.83	51.77	14.56	40.51	3.71	-0.08
	3.46	<0.03	4.47	34.73	2.84	24.42	-1.46	0.47
M3E3P	37.46	4.08	33.37	96.41	46.16	60.12	1.14	0.54
	4.06	<0.03	4.34	50.37	2.53	24.19	3.25	-0.12
M3E5P	3.88	<0.03	4.71	752.99	100.05	55.76	0.48	-0.76
	72.89	55.67	17.22	556.76	17.24	43.54	-0.13	-0.04
M3E7P	10.24	<0.03	10.24	239.32	77.26	41.41	7.45	1.20
	20.87	12.15	8.72	327.33	19.35	40.16	7.71	1.04
M3E8dP	31.60	20.38	11.22	122.14	6.36	28.72	5.43	0.92
	117.03	104.38	12.65	102.61	9.62	25.64	0.86	0.03
M3W3L	6.27	<0.03	6.31	249.24	52.49	41.22	3.55	0.78
	6.39	1.13	5.25	223.08	10.43	26.76	3.96	0.58
M3W5L	5.80	<0.03	5.80	24.55	2.84	31.76	3.41	0.56
	2.20	<0.03	2.61	26.87	1.23	33.85	-0.68	0.18
M3W6L	3.52	-0.78	4.30	470.86	329.68	35.61	7.37	1.80
	9.73	1.82	7.91	182.28	90.70	27.28	6.48	1.28
M3W9L	8.10	<0.03	8.79	44.64	13.59	30.38	6.12	1.08
	2.91	0.14	2.77	50.87	2.35	27.35	8.16	1.67
M4E10S	11.21	<0.03	17.37	42.47	18.09	27.70	7.05	1.50
	4.10	<0.03	5.52	38.90	12.22	22.44	10.45	1.82
M4E12R	3.58	<0.03	4.68	19.22	2.32	42.13	5.00	0.38
	2.87	<0.03	3.50	13.94	5.52	32.53	4.73	0.41
M4E1L	6.43	<0.03	7.33	20.62	5.66	39.65	1.68	-0.16
	5.04	<0.03	5.30	9.09	2.56	24.45	9.60	1.54
M4E2L	7.26	<0.03	10.52	45.38	2.84	70.88	-11.94	-2.34
	2.94	0.87	2.07	22.59	0.89	33.58	-0.43	-0.52
M4E3L	12.61	8.20	4.41	606.14	229.18	42.45	-2.58	-1.54
	13.08	10.85	2.22	178.13	8.02	42.39	-1.49	-0.46
M4E5L	13.38	<0.03	15.26	30.35	2.24	57.61	-9.26	-1.77
	2.76	0.65	2.11	48.17	1.51	38.13	-7.70	-1.58
M4W5P	7.47	4.66	2.80	34.10	0.45	35.44	-1.71	-0.68
	1.87	0.92	0.95	20.20	1.03	34.22	-7.27	-1.02
M4W7P	1.95	<0.03	2.67	15.72	1.07	26.44	5.69	1.44
	0.36	<0.03	0.77	7.34	2.58	25.05	6.14	0.88
M4W8dP	1.47	<0.03	2.65	14.26	0.74	32.46	-0.58	-1.38
	0.88	<0.03	1.43	9.21	1.21	34.10	-3.64	-0.94
M4W8P	6.66	0.21	6.45	153.14	116.30	94.70	-6.14	-1.64
	5.46	0.77	4.69	129.58	20.31	73.88	-8.33	-1.38
M4W9P	8.61	<0.03	12.53	34.29	3.94	56.27	-0.18	0.09
	13.11	<0.03	13.22	11.25	2.70	44.97	0.63	0.05

Table 5. Data from all surface water samples. The chemical constituents from left to right are: Alkalinity (Alk), Chloride (Cl^-), Sulfate (SO_4^{2-}), Sodium (Na^+), Potassium (K^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Ammonium (NH_4^+), Charge Balance Error (CBE), Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP) and Deuterium, and Oxygen-18. Missing samples are represented by the symbol *.

Site	Date	Alk (mg/L as HCO_3^-)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	NH_4^+ (mg/L)	CBE	TP (µg/L)	SRP (µg/L)	δD ‰	δO18 %
M1Eb	10/13/08	201.19	17.80	0.03	13.66	1.57	3.76	50.67	0.05	-0.04	15.00	2.00	1.29	0.21
M1Wb	10/13/08	185.17	17.31	0.03	14.11	1.80	3.93	48.54	0.04	-0.02	*	*	3.37	-0.28
M2Eb	10/13/08	160.46	17.09	0.06	13.55	1.76	3.83	44.65	0.00	0.01	6.00	2.00	3.30	-0.09
M2Wb	10/13/08	163.51	17.66	0.00	13.86	1.74	3.88	47.40	0.00	0.02	8.00	2.00	0.75	0.07
M3Eb	10/13/08	144.75	17.35	0.03	13.44	1.41	3.76	41.44	0.00	0.02	8.00	2.00	2.17	0.57
M3Wb	10/13/08	151.77	17.48	0.03	13.46	1.60	3.81	43.54	0.00	0.02	7.00	2.00	2.27	0.36
M4Eb	10/13/08	149.79	16.67	0.08	13.55	1.72	3.82	44.36	0.00	0.04	7.00	2.00	2.56	0.22
M4Wb	10/13/08	176.17	18.16	0.06	13.42	1.72	3.83	45.65	0.00	-0.03	7.00	2.00	3.72	1.90
M1Eb	5/4/09	195.24	26.32	0.01	36.70	6.89	8.33	60.27	0.12	0.16	14.00	2.00	29.57	5.46
M1Wb	5/4/09	189.75	52.75	0.00	36.71	5.89	8.07	58.17	0.17	0.07	11.00	2.00	27.48	5.35
M2Eb	5/4/09	185.07	49.22	0.01	31.56	5.49	7.16	48.80	0.14	0.01	11.00	2.00	27.48	4.78
M2Wb	5/4/09	188.94	47.42	0.07	30.18	5.26	6.93	54.50	0.14	0.03	11.00	2.00	21.62	4.31
M3Eb	5/4/09	149.07	49.01	0.00	34.37	5.25	7.21	46.39	0.17	0.09	11.00	2.00	*	*
M3Wb	5/4/09	158.84	*	*	29.83	4.70	6.77	48.22	0.00		18.00	2.00	23.43	4.81
M4Eb	5/4/09	163.51	55.45	0.03	34.91	6.09	7.12	45.96	0.15	0.04	2.00	2.00	24.15	5.39
M4Wb	5/4/09	158.43	50.46	0.00	31.64	5.28	6.87	46.12	0.00	0.04	13.00	2.00	28.44	5.23

Table 6. The average groundwater concentrations and standard errors for chemical constituents in the ridges, sloughs, deep wells and tree islands the wet and dry season of 2008-2009.

		Ridge				Slough				Deep				Tree Islands			
		Wet Season		Dry Season		Wet Season		Dry Season		Wet Season		Dry Season		Wet Season		Dry Season	
Chemical Constituents	Units	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE
Temperature	° C	**27.0**	0.1	**23.8** [b]	0.2	**27.3**	0.1	**25.1** [a,b,c]	0.3	**26.6**	0.2	**23.5** [b]	0.2	**27.1**	0.1	**23.9** [b]	0.1
Conductivity	$\mu S\ cm^{-1}$	**514.30** [c,d]	90.21	**515.25** [c,d]	81.24	**681.38** [d]	63.11	**668.40**	71.45	**1025.00** [a]	121.44	**925.00** [a]	109.58	**1131.74** [a,b]	52.67	**914.71** [a]	38.20
pH		**6.34**	0.42	**6.46**	0.31	**6.78**	0.15	**6.97**	0.11	**6.80**	0.07	**6.62**	0.03	**6.50**	0.02	**6.63**	0.04
Total Alkalinity	mg L^{-1}	**277.07** [d]	36.27	**339.13** [d]	53.53	**432.81**	54.42	**377.63**	43.43	**573.79**	58.79	**564.42**	60.78	**655.47** [a]	40.89	**546.06** [a]	25.33
Chloride	mg L^{-1}	**29.54**	2.45	**30.95**	3.71	**25.23**	2.39	**27.66** [d]	1.53	**35.76**	5.54	**43.42**	9.30	**42.21**	2.65	**44.01** [b]	1.98
Sulfate	mg L^{-1}	**0.05**	0.01	**0.01**	0.01	**0.35**	0.26	**0.06**	0.03	**0.03**	0.02	**0.01**	0.01	**0.78**	0.51	**0.03**	0.01
Sodium	mg L^{-1}	**23.21**	2.01	**23.69**	3.52	**24.56**	2.56	**19.02** [d]	0.93	**30.87**	4.46	**30.60**	4.84	**33.37**	1.71	**29.13** [b]	1.40
Potassium	mg L^{-1}	**2.99**	0.94	**2.14**	0.78	**10.30**	2.29	**4.66**	1.56	**6.67**	1.99	**5.04**	0.73	**6.45**	0.81	**4.75**	0.69
Magnesium	mg L^{-1}	**8.55** [d]	1.09	**8.81**	0.45	**9.58** [d]	0.53	**7.75** [d]	1.40	**12.69**	0.36	**11.83**	0.72	**14.69** [a,b]	0.63	**13.09** [b]	0.64
Calcium	mg L^{-1}	**82.86** [d]	11.25	**80.56** [c,d]	19.06	**114.51**	19.20	**113.77**	19.27	**161.67**	19.09	**171.51** [c]	26.91	**176.74** [a]	9.69	**153.47** [a]	7.63
Nitrate+Nitrite	µg L^{-1}	**6.12**	1.84	**5.44**	3.98	**7.45**	2.46	**5.85**	0.99	**11.03**	6.92	**32.32**	28.29	**8.23**	1.19	**10.82**	2.46
Total Phosphorus	µg L^{-1}	**29.22**	7.83	**24.60**	9.07	**48.82**	22.56	**24.63**	4.03	**42.55**	26.54	**34.41**	22.75	**123.97**	33.39	**81.04**	21.44
Soluble Reactive Phosphorus	µg L^{-1}	**12.76**	3.56	**9.20**	6.62	**9.49**	3.78	**7.03**	1.85	**5.86**	2.16	**5.42**	2.30	**52.14**	14.75	**13.09**	3.62
Total Organic Carbon	mg L^{-1}	**34.56**	4.24	**29.31**	5.31	**33.97**	2.36	**26.07**	3.20	**27.22**	2.16	**26.00**	2.90	**42.23**	2.86	**35.52**	2.27
δD	‰	**4.52**	0.57	**2.89**	3.04	**5.26**	1.19	**4.95**	1.72	**2.92**	1.37	**0.53**	1.93	**1.27**	0.79	**1.29**	0.92
δO^{18}	‰	**0.36**	0.17	**0.56**	0.14	**0.98**	0.37	**0.83**	0.31	**0.29**	0.56	**-0.11**	0.35	**-0.08**	0.18	**0.08**	0.16

Significant difference (α=0.05) detected between a. Ridge, b. Slough, c. Deep and D. Tree Islands

Table 7. The average groundwater concentrations and standard errors for chemical constituents in the ridges, sloughs, deep wells and tree islands the wet and dry season of 2008-2009.

Chemical Constituents	Units	Season	Low Density Tree Planting Quadrant Average	Low Density Tree Planting Quadrant SE	Center of Tree island Average	Center of Tree island SE	High Density Tree Planting quadrant Average	High Density Tree Planting quadrant SE
Total Alkalinity	mg L^{-1}	Wet	**574.37**	30.95	**682.71**	64.62	**685.51**	75.17
		Dry	**460.91**	53.03	**570.58**	28.51	**551.67**	73.78
Chloride	mg L^{-1}	Wet	**34.41**	3.51	**48.27**	3.74	**39.65**	4.08
		Dry	**40.38**	3.96	**44.69**	3.17	**46.44**	3.87
Sulfate	mg L^{-1}	Wet	**0.03**	0.01	**1.49**	0.98	**0.04**	0.00
		Dry	**0.02**	0.01	**0.05**	0.02	**0.02**	0.01
Sodium	mg L^{-1}	Wet	**28.39**	2.41	**35.59**	2.68	**32.41**	2.46
		Dry	**25.98**	2.59	**30.04**	2.05	**30.77**	3.47
Potassium	mg L^{-1}	Wet	**3.62**	0.90	**7.43**	0.90	**7.07**	1.96
		Dry	**2.02**	0.58	**5.63**	0.82	**5.71**	2.25
Magnesium	mg L^{-1}	Wet	**13.51**	0.78	**15.57**	1.02	**15.08**	0.99
		Dry	**11.58**	1.21	**13.67**	0.85	**12.27**	1.63
Calcium	mg L^{-1}	Wet	**160.09**	8.26	**184.84**	15.57	**180.45**	16.98
		Dry	**135.12**	16.69	**159.57**	9.80	**148.83**	20.71
Nitrate+Nitrite	µg L^{-1}	Wet	**9.26**	3.61	**7.97**	1.23	**8.80**	1.55
		Dry	**6.62**	1.61	**13.76**	4.88	**9.80**	2.37
Ammonium	mg L^{-1}	Wet	**3.91**	0.78	**7.06**	1.16	**6.58**	1.71
		Dry	**2.78**	1.02	**4.17**	0.62	**4.49**	1.84
Total Phosphors	µg L^{-1}	Wet	**48.71**	8.32	**136.97**	54.49	**147.57**	65.39
		Dry	**26.93**	6.56	**94.32**	37.40	**118.45**	47.59
Soluble Reactive Phosphorus	µg L^{-1}	Wet	**15.53**	6.20	**62.17**	24.76	**57.25**	24.69
		Dry	**5.05**	2.04	**19.61**	7.04	**8.46**	2.21
Total Organic Carbon	mg L^{-1}	Wet	**35.03**	4.74	**46.26**	4.77	**38.12**	2.31
		Dry	**34.96**	5.66	**37.71**	3.64	**32.24**	2.55
δD	‰	Wet	**1.50**	0.69	**-0.29**	1.26	**3.85**	1.05
		Dry	**4.26**	1.36	**-1.72**	1.12	**4.92**	1.82
δO^{18}	‰	Wet	**0.24**	0.12	**-0.53**	0.25	**0.39**	0.35
		Dry	**0.36**	0.32	**-0.35**	0.19	**0.79**	0.32

Table 8. Isotopic values of stem water and soil water. Samples were taken from 6 of the 8 tree islands, the first three letters of the sample id indicate the tree islands, the next letter indicates the tree planting density quadrant H represents high density while L represents low density, the following letter indicates the elevation, U represents the high elevation while L represents low elevation, the last letter indicates the soil water or species, C represents *Chrysobalanus icaco*, D represents *Myrica cerifera*, P represents *Annona glabra* and S represents soil water.

Sample	Date	δD (‰)	δO^{18} (‰)	Sample	Date	δD (‰)	δO^{18} (‰)	Sample	Date	δD (‰)	δO^{18} (‰)
M1EHLC	10/6/08	-6.85	0.79	M1WHUD	10/6/08	3.85	0.24	M2WHUP	10/6/08	12.01	2.09
M1WHLC	10/6/08	-4.10	0.36	M2WHLD	10/6/08	-0.53	1.45	M2EHUP	10/6/08	7.68	0.64
M1WHLC	10/6/08	-1.89	0.71	M2WHLD	10/6/08	8.74	1.61	M2EHUP	10/6/08	2.43	1.31
M1WHLC	10/6/08	6.62	1.32	M2WHLD	10/6/08	10.57	1.77	M3EHLP	10/6/08	8.98	1.69
M1EHUC	10/6/08	-5.17	-0.09	M2EHLD	10/6/08	5.78	1.29	M3EHLP	10/6/08	9.74	1.69
M1EHUC	10/6/08	-3.36	-0.87	M2WHUD	10/6/08	7.12	1.28	M3EHUP	10/6/08	4.82	0.72
M1EHUC	10/6/08	-1.99	0.20	M2WHUD	10/6/08	0.16	1.28	M4WHLP	10/6/08	-0.88	1.07
m1whuc	10/6/08	-0.65	0.11	M2WHUD	10/6/08	15.19	1.98	M4WHLP	10/6/08	4.18	0.99
M1WHUC	10/6/08	-8.14	-1.33	M3EHLD	10/6/08	5.31	1.02	M4WHLP	10/6/08	5.91	0.81
M2WHCC	10/6/08	6.20	1.61	M3EHLD	10/6/08	7.91	0.76	M1ELLP	10/6/08	11.76	1.54
M2WHLC	10/6/08	4.22	1.51	M3EHUD	10/6/08	0.06	0.77	M1ELLP	10/6/08	3.33	1.73
M2WHLC	10/6/08	6.81	1.00	M3EHUD	10/6/08	1.58	0.77	M1WLLP	10/6/08	0.83	1.17
M2EHLC	10/6/08	9.33	1.56	M3EHUD	10/6/08	3.14	1.20	M1ELUP	10/6/08	1.34	-0.31
M2WHUC	10/6/08	-3.82	0.82	M3EHUD	10/6/08	4.97	0.87	M1WLUP	10/6/08	8.43	1.36
M2WHUC	10/6/08	2.38	1.05	M4WHUD	10/6/08	-6.17	0.83	M1WLUP	10/6/08	-7.88	-0.83
M2WHUC	10/6/08	4.95	0.33	M4WHUD	10/6/08	0.02	0.70	M1WLLP	10/6/08	5.36	0.98
M2EHUC	10/6/08	6.60	0.88	M1ELLD	10/6/08	1.02	-0.03	M1WLLP	10/6/08	14.02	2.06
M2EHUC	10/6/08	6.36	0.82	M1ELLD	10/6/08	5.34	0.69	M2WLUP	10/6/08	12.98	1.98
M3EHLC	10/6/08	4.38	1.67	M1WLLD	10/6/08	13.63	1.95	M2WLLP	10/6/08	-1.31	1.24
M3EHUC	10/6/08	0.31	0.46	M1WLLD	10/6/08	-1.30	1.44	M2WLLP	10/6/08	5.97	0.41
M3EHUC	10/6/08	7.28	1.66	M1WLLD	10/6/08	5.66	0.42	M2ELLP	10/6/08	9.96	1.11
M4WHLC	10/6/08	4.04	0.42	M1WLLD	10/6/08	12.75	2.00	M2WLUP	10/6/08	-0.24	1.71
M4WHUC	10/6/08	-4.90	0.81	M1ELUD	10/6/08	-10.15	-1.64	M2WLUP	10/6/08	4.98	0.28
M4WHUC	10/6/08	-3.06	-0.30	M1ELUD	10/6/08	-1.97	0.27	M2ELUP	10/6/08	3.39	0.72
M4WHUC	10/6/08	-3.06	0.49	M1ELUD	10/6/08	1.40	-0.34	M2ELUP	10/6/08	9.64	1.55
M4WHUC	10/6/08	1.03	0.08	M1WLUD	10/6/08	1.27	-0.17	M3ELLP	10/6/08	-0.75	1.28
M1ELLC	10/6/08	5.41	0.95	M1WLUD	10/6/08	-6.47	-1.40	M3ELUP	10/6/08	-2.51	1.37
M1ELLC	10/6/08	-5.33	-0.27	M1WLUD	10/6/08	0.84	-0.05	M3ELUP	10/6/08	-0.63	0.15
M1WLLC	10/6/08	-2.08	0.38	M2WLLD	10/6/08	10.96	1.96	M3ELUP	10/6/08	6.64	2.45
M1WLLC	10/6/08	1.45	1.11	M2ELLD	10/6/08	6.58	1.40	M1EHUS	10/6/08	13.04	1.90
M1ELUC	10/6/08	-5.94	-1.11	M2WLUD	10/6/08	8.32	1.22	M1WHUS	10/6/08	-0.91	-0.61
M1WLUC	10/6/08	-1.69	-0.53	M2ELUD	10/6/08	3.50	1.62	M1WHUS	10/6/08	5.25	0.49
M1WLUC	10/6/08	-4.92	-0.63	M2ELUD	10/6/08	7.24	1.13	M1ELUS	10/6/08	-5.41	-0.99
M1WLUC	10/6/08	-6.90	-0.39	M2ELUD	10/6/08	7.47	1.03	M1WUS	10/6/08	-3.88	-1.83
M1ELLC	10/6/08	4.63	0.64	M3ELLD	10/6/08	5.50	1.04	M3EUS	10/6/08	5.46	1.67
M1ELUC	10/6/08	-4.67	-0.22	M3ELLD	10/6/08	8.53	2.01				
M2WLLC	10/6/08	-0.50	0.97	M3WLLD	10/6/08	4.76	1.75				
M2ELLC	10/6/08	-1.73	1.00	M3ELUD	10/6/08	10.73	2.31				
M2WLUC	10/6/08	-5.60	0.28	M4WLLD	10/6/08	0.37	1.57				
M2WLUC	10/6/08	5.15	1.56	M4WLLD	10/6/08	10.89	1.40				
M2ELUC	10/6/08	4.96	0.88	M4WLUD	10/6/08	-5.88	-0.38				
M3ELLC	10/6/08	8.64	1.67	M4WLUD	10/6/08	-1.39	-0.47				
M3ELUC	10/6/08	-1.25	0.59	M1EHLP	10/6/08	2.46	0.73				
M3ELUC	10/6/08	5.04	0.62	M1EHLP	10/6/08	6.75	1.41				
M4WLLC	10/6/08	-3.15	0.10	M1WHLP	10/6/08	13.40	2.51				
M4WLLC	10/6/08	2.69	1.16	M1WHLP	10/6/08	5.02	0.60				
M4WLLC	10/6/08	2.97	1.59	M1EHUP	10/6/08	0.09	1.72				
M4WLUC	10/6/08	1.19	0.80	M1EHUP	10/6/08	3.60	0.38				
M1WHLD	10/6/08	0.68	1.42	M1EHUP	10/6/08	4.23	0.88				
M1WHLD	10/6/08	8.36	1.71	M1WHUP	10/6/08	2.67	0.40				
M1EHUD	10/6/08	-4.39	-0.59	M1WHUP	10/6/08	5.56	1.06				
M1EHUD	10/6/08	-0.88	0.98	M1WHLP	10/6/08	5.65	1.01				
M1EHUD	10/6/08	4.84	0.39	M2WHLP	10/6/08	11.28	1.69				
M1WHUD	10/6/08	0.64	-0.21	M2EHLP	10/6/08	6.01	1.52				

Table 9. Isotopic values of stem water and soil water. Samples were taken from 6 of the 8 tree islands, the first three letters of the sample id indicate the tree islands, the next letter indicates the tree planting density quadrant H represents high density while L represents low density, the following letter indicates the elevation, U represents the high elevation while L represents low elevation, the last letter indicates the soil water or species, C represents *Chrysobalanus icaco*, D represents *Myrica cerifera*, P represents *Annona glabra* and S represents soil water.

Name	Date	δD (‰)	δ18O (‰)	Name	Date	δD (‰)	δ18O (‰)
M1EHLC	5/5/09	1.52	1.23	M1WLLD	5/5/09	19.10	4.57
M1EHLD	5/5/09	12.8	3.3	M1WLLP	5/5/09	23.4	4.2
M1EHLP	5/5/09	18.1	2.1	M1WLLP	5/5/09	15.85	4.18
M1EHLP	5/5/09	19.4	3.9	M1WLLS-10	5/5/09	2.24	0.13
M1EHLP	5/5/09	25.51	4.02	M1WLLS-10	5/5/09	5.39	0.51
M1EHLP	5/5/09	15.44	3.09	M1WLUC	5/5/09	-2.4	-0.4
M1EHLS-10	5/5/09	17.87	3.06	M1WLUC	5/5/09	-11.00	-1.31
M1EHLS-20	5/5/09	11.95	1.91	M1WLUD	5/5/09	-4.1	-0.2
M1EHUC	5/5/09	-2.25	0.47	M1WLUD	5/5/09	-5.4	-0.1
M1EHUC	5/5/09	-4.05	0.03	M1WLUP	5/5/09	3.26	-0.19
M1EHUC	5/5/09	0.14	0.45	M1WLUP	5/5/09	-3.26	-0.80
M1EHUD	5/5/09	11.0	1.3	M1WLUP	5/5/09	-1.12	0.45
M1EHUD	5/5/09	-0.6	0.8	M1WLUS-10	5/5/09	0.5	0.0
M1EHUD	5/5/09	-0.59	-0.01	M2EHC	5/5/09	2.69	1.05
M1EHUP	5/5/09	1.6	0.2	M2EHLC	5/5/09	-34.29	-14.68
M1EHUP	5/5/09	1.87	-0.95	M2EHLC	5/5/09	26.06	3.93
M1EHUP	5/5/09	19.04	2.78	M2EHLC	5/5/09	1.07	1.60
M1ELLC	5/5/09	7.02	1.03	M2EHLC	5/5/09	2.91	0.10
M1ELLC	5/5/09	7.03	1.90	M2EHLD	5/5/09	19.4	3.4
M1ELLC	5/5/09	-0.78	0.72	M2EHLD	5/5/09	18.2	1.8
M1ELLD	5/5/09	9.20	0.62	M2EHLD	5/5/09	21.8	3.2
M1ELLD	5/5/09	6.65	0.59	M2EHLP	5/5/09	20.43	3.53
M1ELLP	5/5/09	10.7	2.6	M2EHLP	5/5/09	29.68	5.17
M1ELLP	5/5/09	14.2	1.4	M2EHLS-10	5/5/09	14.01	1.77
M1ELLS-10	5/5/09	2.5	0.5	M2EHUC	5/5/09	-5.4	-0.2
M1ELLS-20	5/5/09	3.82	1.22	M2EHUC	5/5/09	6.65	0.59
M1ELUC	5/5/09	-3.89	-0.06	M2EHUC	5/5/09	-2.25	0.11
M1ELUC	5/5/09	-8.43	-0.14	M2EHUC	5/5/09	2.49	1.24
M1ELUC	5/5/09	-5.20	-0.55	M2EHUD	5/5/09	-2.6	-0.1
M1ELUD	5/5/09	-0.8	-0.5	M2EHUD	5/5/09	3.28	0.66
M1ELUD	5/5/09	6.93	0.23	M2EHUD	5/5/09	-4.07	0.21
M1ELUP	5/5/09	-5.3	-1.0	M2EHUD	5/5/09	1.20	0.08
M1ELUP	5/5/09	3.50	-0.20	M2EHUP	5/5/09	20.02	3.55
M1ELUP	5/5/09	-3.94	0.62	M2EHUS-10	5/5/09	1.22	0.08
M1ELUP	5/5/09	-7.95	-1.66	M2EHUS-10	5/5/09	1.91	-0.11
M1ELUS	5/5/09	-4.43	-0.33	M2EHUS-20	5/5/09	4.83	0.36
M1ELUS-20	5/5/09	6.56	1.20	M2ELLC	5/5/09	10.6	2.5
M1WHLC	5/5/09	7.92	1.04	M2ELLC	5/5/09	-1.33	-0.82
M1WHLC	5/5/09	-0.63	0.90	M2ELLC	5/5/09	0.90	0.85
M1WHLD	5/5/09	15.8	2.1	M2ELLC	5/5/09	4.60	1.02
M1WHLD	5/5/09	12.69	-6.99	M2ELLD	5/5/09	-7.0	0.4
M1WHLD	5/5/09	11.92	2.92	M2ELLD	5/5/09	32.41	4.82
M1WHLP	5/5/09	9.7	2.1	M2ELLD	5/5/09	5.11	0.86
M1WHLP	5/5/09	19.88	3.29	M2ELLP	5/5/09	2.4	0.4
M1WHLS-10	5/5/09	18.51	3.00	M2ELLS-10	5/5/09	6.24	1.11
M1WHLS-10	5/5/09	6.07	1.11	M2ELLS-20	5/5/09	6.54	0.97
M1WHLS-20	5/5/09	22.48	3.62	M2ELUC	5/5/09	-1.39	0.17
M1WHLS-20	5/5/09	11.89	2.25	M2ELUC	5/5/09	7.93	-3.04
M1WHUC	5/5/09	-2.04	0.12	M2ELUC	5/5/09	1.30	-0.02
M1WHUC	5/5/09	-0.14	0.27	M2ELUD	5/5/09	-6.2	-0.7
M1WHUC	5/5/09	-5.06	-0.64	M2ELUD	5/5/09	-4.4	0.2
M1WHUD	5/5/09	-1.3	-1.1	M2ELUD	5/5/09	2.90	0.11
M1WHUD	5/5/09	-4.70	0.14	M2ELUP	5/5/09	-1.90	-0.43
M1WHUP	5/5/09	8.83	-5.57	M2ELUP	5/5/09	0.67	0.19
M1WHUP	5/5/09	5.57	2.51	M2ELUS-10	5/5/09	6.93	1.20
M1WHUP	5/5/09	6.86	2.85	M2ELUS-10	5/5/09	1.73	0.58
M1WHUP	5/5/09	-5.14	-0.70	M2ELUS-20	5/5/09	-0.66	-0.09
M1WHUS-20	5/5/09	-2.38	-0.63	M2ELUS-20	5/5/09	1.19	0.21
M1WLLC	5/5/09	-38.43	-14.47	M2WHLC	5/5/09	15.11	2.53
M1WLLC	5/5/09	16.18	4.33	M2WHLC	5/5/09	8.15	2.06
M1WLLC	5/5/09	4.62	2.36	M2WHLD	5/5/09	15.9	4.4
M1WLLD	5/5/09	12.6	2.2	M2WHLD	5/5/09	-3.26	-0.80

Table 10. Isotopic values of stem water and soil water. Samples were taken from 6 of the 8 tree islands, the first three letters of the sample id indicate the tree islands, the next letter indicates the tree planting density quadrant H represents high density while L represents low density, the following letter indicates the elevation, U represents the high elevation while L represents low elevation, the last letter indicates the soil water or species, C represents *Chrysobalanus icaco*, D represents *Myrica cerifera*, P represents *Annona glabra* and S represents soil water.

Name	Date	δD (‰)	δ18O (‰)	Name	Date	δD (‰)	δ18O (‰)
M2WHLP	5/5/09	28.0	3.4	M3WLLC	5/5/09	1.2	1.5
M2WHLP	5/5/09	34.4	2.8	M3WLLC	5/5/09	-1.54	-0.07
M2WHLP	5/5/09	19.39	3.05	M3WLLC	5/5/09	6.44	1.32
M2WHLS-10	5/5/09	17.38	3.03	M3WLLC	5/5/09	7.11	1.80
M2WHLS-10	5/5/09	12.38	2.18	M3WLLD	5/5/09	20.02	3.55
M2WHLS-20	5/5/09	4.6	1.3	M3WLLD	5/5/09	-13.15	-0.97
M2WHLS-20	5/5/09	18.18	2.83	M3WLLD	5/5/09	15.72	2.91
M2WHUC	5/5/09	0.67	0.19	M3WLLP	5/5/09	4.8	1.9
M2WHUC	5/5/09	-3.22	-1.11	M3WLLP	5/5/09	4.4	2.6
M2WHUC	5/5/09	-3.01	1.04	M3WLLS-10	5/5/09	15.60	3.05
M2WHUD	5/5/09	5.9	0.9	M3WLLS-20	5/5/09	8.23	2.67
M2WHUD	5/5/09	5.18	-1.04	M3WLUC	5/5/09	7.1	1.9
M2WHUD	5/5/09	11.34	1.71	M3WLUC	5/5/09	3.28	0.66
M2WHUP	5/5/09	4.93	0.01	M3WLUC	5/5/09	2.27	0.49
M2WHUP	5/5/09	-0.88	1.59	M3WLUD	5/5/09	4.2	0.9
M2WHUP	5/5/09	1.77	1.57	M3WLUD	5/5/09	-4.2	0.5
M2WHUP	5/5/09	3.07	0.93	M3WLUD	5/5/09	4.36	2.06
M2WLLC	5/5/09	5.81	1.46	M3WLUP	5/5/09	8.01	2.33
M2WLLC	5/5/09	-1.70	-0.25	M3WLUP	5/5/09	10.28	3.04
M2WLLD	5/5/09	14.87	3.06	M3WLUS-10	5/5/09	3.97	1.33
M2WLLD	5/5/09	9.20	0.62	M3WLUS-10	5/5/09	0.65	-0.01
M2WLLD	5/5/09	35.04	5.65	M3WLUS-20	5/5/09	4.64	0.82
M2WLLP	5/5/09	19.3	3.6	M3WLUS-20	5/5/09	0.05	0.54
M2WLLP	5/5/09	14.5	2.5	M4WHLC	5/5/09	10.21	1.25
M2WLLP	5/5/09	14.21	2.27	M4WHLC	5/5/09	11.64	1.52
M2WLLS-10	5/5/09	15.08	3.52	M4WHLC	5/5/09	4.98	1.75
M2WLLS-10	5/5/09	18.24	3.07	M4WHLD	5/5/09	0.6	1.5
M2WLLS-20	5/5/09	12.40	2.10	M4WHLD	5/5/09	15.72	2.91
M2WLUC	5/5/09	-1.2	0.4	M4WHLD	5/5/09	6.55	0.84
M2WLUC	5/5/09	15.11	2.53	M4WHLP	5/5/09	4.5	2.1
M2WLUC	5/5/09	4.38	0.64	M4WHLP	5/5/09	6.56	1.20
M2WLUD	5/5/09	4.9	1.1	M4WHLP	5/5/09	5.30	0.98
M2WLUD	5/5/09	-5.5	1.1	M4WHLP	5/5/09	1.81	0.41
M2WLUD	5/5/09	-0.24	1.53	M4WHLS-10	5/5/09	14.00	2.35
M2WLUD	5/5/09	4.48	0.35	M4WHLS-20	5/5/09	9.74	1.91
M2WLUP	5/5/09	-3.0	0.7	M4WHUC	5/5/09	-15.0	-0.3
M2WLUP	5/5/09	25.51	4.02	M4WHUC	5/5/09	-6.38	-0.18
M2WLUP	5/5/09	5.76	1.60	M4WHUC	5/5/09	-0.66	0.57
M2WLUS-10	5/5/09	0.21	1.10	M4WHUD	5/5/09	-13.15	-0.97
M2WLUS-20	5/5/09	2.6	0.7	M4WHUD	5/5/09	11.34	1.71
M3WHLC	5/5/09	8.7	2.5	M4WHUD	5/5/09	-3.19	-0.02
M3WHLC	5/5/09	1.44	0.69	M4WHUD	5/5/09	-4.0	0.0
M3WHLC	5/5/09	14.21	2.27	M4WHUS-10	5/5/09	1.47	-0.06
M3WHLD	5/5/09	19.04	2.78	M4WHUS-20	5/5/09	-0.99	-0.39
M3WHLD	5/5/09	22.44	2.60	M4WHUS-20	5/5/09	-5.10	-0.72
M3WHLD	5/5/09	13.95	2.22	M4WLLC	5/5/09	26.06	3.93
M3WHLP	5/5/09	7.7	1.8	M4WLLC	5/5/09	15.50	2.95
M3WHLP	5/5/09	0.13	1.00	M4WLLC	5/5/09	0.92	1.23
M3WHLP	5/5/09	7.73	3.03	M4WLLD	5/5/09	-0.88	1.59
M3WHLS-10	5/5/09	10.13	2.09	M4WLLD	5/5/09	1.01	1.44
M3WHUC	5/5/09	-3.12	0.30	M4WLLD	5/5/09	7.73	1.26
M3WHUC	5/5/09	3.27	0.03	M4WLLS-10	5/5/09	5.24	1.52
M3WHUD	5/5/09	0.37	0.17	M4WLLS-20	5/5/09	2.64	0.23
M3WHUD	5/5/09	5.81	1.46	M4WLUC	5/5/09	-4.6	-0.7
M3WHUD	5/5/09	-2.64	0.85	M4WLUC	5/5/09	1.77	-0.32
M3WHUD	5/5/09	1.57	1.43	M4WLUC	5/5/09	1.59	0.08
M3WHUP	5/5/09	5.9	0.4	M4WLUD	5/5/09	-1.33	-0.82
M3WHUP	5/5/09	0.2	1.8	M4WLUD	5/5/09	-3.22	-1.11
M3WHUP	5/5/09	9.05	2.64	M4WLUD	5/5/09	-15.8	-0.9
M3WHUS-10	5/5/09	8.94	1.49	M4WLUS-10	5/5/09	0.93	-0.24
M3WHUS-10	5/5/09	5.74	1.70	M4WLUS-20	5/5/09	-4.28	-0.83
M3WHUS-20	5/5/09	3.23	0.73	M4WLUS-20	5/5/09	-3.23	-0.76
M3WHUS-20	5/5/09	0.27	0.71				

Table 11. Pearson correlation coefficients of various chemical constituents tested in the groundwater.

October	Temp (ºC)	Conductivity (uS/cm)	pH	Alkalinity (mg/L HCO_3^-)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	N+N (µg/L)	NO3- (µg/L)	NO2- (µg/L)	NH_4^+ (mg/L)	TP (µg/L)	SRP (µg/L)	TOC (mg/L)	δD ‰	δO18 ‰
Temp(ºC)	1	-0.227	-0.064	-0.153	-0.269	**-.331***	-0.143	0.023	-0.202	- 0.243	- 0.027	- 0.026	-0.014	-0.073	0.177	0.142	-0.091	**.394****	**.392****
Conductivity (uS/cm)		1	-0.088	**.973****	**.780****	0.269	**.818****	**.471****	**.869****	**.959****	0.211	.301*	0.034	**.547****	**.536****	0.235	**.426****	**-.523****	**-.460****
pH			1	0.038	-0.197	0.01	-0.054	0.107	-0.193	0.057	- 0.114	0.127	-0.232	-0.217	- 0.071	-0.26	-0.127	0.08	0.077
Alkalinity (mg/L HCO_3^-)				1	**.739****	0.285	**.812****	**.473****	**.822****	**.954****	0.144	0.261	-0.017	**.491****	**.597****	0.23	**.437****	**-.535****	**-.483****
Cl^- (mg/L)					1	0.121	**.795****	**.463****	**.745****	**.714****	0.137	0.193	0.024	**.629****	**.501****	0.299	**.484****	**-.480****	**-.507****
SO_4^{2-} (mg/L)						1	**.303***	- 0.145	0.206	**.376***	0.122	- 0.085	0.211	-0.126	- 0.084	- 0.104	0.299	**-.569****	**-.399****
Na^+ (mg/L)							1	**.495****	**.728****	**.756****	0.279	0.224	0.173	**.502****	**.588****	0.277	**.594****	**-.459****	**-.429****
K^+ (mg/L)								1	**.340***	**.349***	0.165	0.299	-0.021	**.636****	**.588****	**.332***	0.135	0.035	-0.085
Mg^{2+} (mg/L)									1	**.836****	0.244	0.123	0.205	**.579****	**.370***	0.295	**.541****	**-.609****	**-.542****
Ca^{2+} (mg/L)										1	0.168	0.297	-0.015	**.394****	**.405****	0.131	**.471****	**-.630****	**-.528****
N+N (µg/L)											1	**.567****	**.794****	0.237	0.056	0.076	0.205	-0.065	-0.004
NO3- (µg/L)												1	-0.05	0.268	0.173	0.042	-0.031	0.013	-0.021
NO2- (µg/L)													1	0.09	-0.06	0.061	0.271	-0.089	0.01
NH_4^+ (mg/L)														1	**.591****	**.631****	0.239	-0.135	-0.291
TP (µg/L)															1	**.746****	0.267	-0.057	-0.148
SRP (µg/L)																1	0.261	-0.022	-0.109
TOC (mg/L)																	1	**-.625****	**-.575****
δD ‰																		1	**.898****
δO18 ‰																			1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 12. Pearson correlation coefficients of various chemical constituents tested in the groundwater.

May	Temp (ºC)	Conductivity (uS/cm)	pH	Alkalinity (mg/L HCO_3^-)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	N+N (μg/L)	NO3- (μg/L)	NO2- (μg/L)	NH_4^+ (mg/L)	TP (μg/L)	SRP (μg/L)	TOC (mg/L)	δD ‰	δO18 ‰
Temp(ºC)	1	0.039	.306*	-0.048	0.045	0.208	0.145	.440**	-0.051	-0.049	0.098	0.096	0.054	.375*	0.182	0.015	-0.147	0.189	0.175
Conductivity (uS/cm)		1	.310*	.918**	.637**	-0.014	.600**	.573**	.714**	.904**	0.248	.308*	-0.116	.636**	.334*	-0.068	0.173	-.366*	-.406**
pH			1	0.219	-0.124	-0.064	-0.13	0.075	0.028	.367*	-0.051	-0.023	-0.134	0.054	-0.001	-0.283	-.373*	0.101	0.147
Alkalinity (mg/L HCO_3^-)				1	.565**	-0.057	.525**	.508**	.753**	.898**	0.195	0.254	-0.14	.565**	0.193	-0.063	0.212	-.422**	-.495**
Cl^- (mg/L)					1	0.168	.736**	.487**	.509**	.564**	0.118	0.164	-0.126	.524**	.305*	0.087	0.243	-.305*	-.308*
SO_4^{2-} (mg/L)						1	0.273	0.247	-0.172	-0.095	.356*	.321*	.316*	0.243	.709**	.385*	0.236	0.063	0.03
Na^+ (mg/L)							1	.638**	.454**	.450**	.377*	.403**	0.081	.511**	.545**	0.141	0.272	-0.174	-0.189
K^+ (mg/L)								1	.490**	.405**	0.214	0.26	-0.08	.625**	.461**	0.045	0.223	-0.289	-0.27
Mg^{2+} (mg/L)									1	.652**	-0.108	-0.068	-0.215	.545**	0.071	-0.092	0.265	-.602**	-.659**
Ca^{2+} (mg/L)										1	0.273	.356*	-0.2	.454**	0.135	-0.149	0.094	-.399**	-.450**
N+N (μg/L)											1	.979**	.579**	0.231	.515**	0.156	0.034	-0.082	-0.059
NO3- (μg/L)												1	.401**	0.252	.486**	0.098	-0.001	-0.097	-0.092
NO2- (μg/L)													1	0.028	.370*	.309*	0.159	0.023	0.109
NH_4^+ (mg/L)														1	.486**	0.082	0.093	-.328*	-.338*
TP (μg/L)															1	.376*	0.227	-0.058	-0.008
SRP (μg/L)																1	0.285	-0.044	-0.014
TOC (mg/L)																	1	-.386*	-.430**
δD ‰																		1	.912**
δO18 ‰																			1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 13. The average groundwater concentrations and standard errors for chemical constituents for the tree islands planted in 2006 (Planting-1) and the tree islands planted in 2007 (Planting-2)

		Wet Season				Dry Season			
		Planting-1		Planting-2		Planting-1		Planting-2	
Chemical constituents		Average	SE	Average	SE	Average	SE	Average	SE
Temperature	° C	26.7*	0.1	27.4*	0.1	23.8	0.2	24.0	0.1
Conductivity	$\mu S\ cm^{-1}$	1203.8*	53.73	1030.3*	77.89	1008.4*	41.95	817.8*	48.72
pH		6.51	0.03	6.55	0.04	6.72*	0.04	6.48*	0.04
Total Alkalinity	$mg\ L^{-1}$	706.10*	42.75	582.65*	58.41	610.87*	29.22	481.76*	29.40
Chloride	$mg\ L^{-1}$	46.25*	2.91	36.40*	3.64	44.52	2.84	43.34	2.85
Sulfate	$mg\ L^{-1}$	1.27	0.88	0.10	0.04	0.01	0.00	0.04	0.02
Sodium	$mg\ L^{-1}$	32.74	1.88	33.44	2.65	27.17	1.42	31.54	2.21
Potassium	$mg\ L^{-1}$	5.80	1.03	7.20	1.08	4.81	1.00	4.76	0.72
Magnesium	$mg\ L^{-1}$	15.69*	0.82	13.16*	0.68	14.07*	0.94	11.75*	0.51
Calcium	$mg\ L^{-1}$	195.33*	11.23	153.52*	11.92	177.43*	7.35	131.01*	10.36
Nitrate+Nitrite	$\mu g\ L^{-1}$	7.94	1.12	9.19	2.37	8.63	2.02	18.20	7.39
Ammonium	$mg\ L^{-1}$	6.64	1.29	5.28	0.73	3.97	0.83	3.66	0.56
Total Phosphorus	$\mu g\ L^{-1}$	88.36	35.94	140.41	48.03	54.05	15.14	98.64	36.08
Soluble Reactive Phosphorus	$\mu g\ L^{-1}$	43.34	19.21	50.57	18.85	8.57	3.69	16.08	5.36
Total Organic Carbon	$mg\ L^{-1}$	42.29	4.39	38.63	2.99	33.92	3.05	34.98	2.96
δD	‰	-0.26*	1.18	3.27*	0.53	0.44	1.42	2.02	0.83
δO^{18}	‰	-0.47*	0.26	0.42*	0.16	-0.12	0.23	0.25	0.16

* significant difference detected between plantings using a t-test (α=0.1)

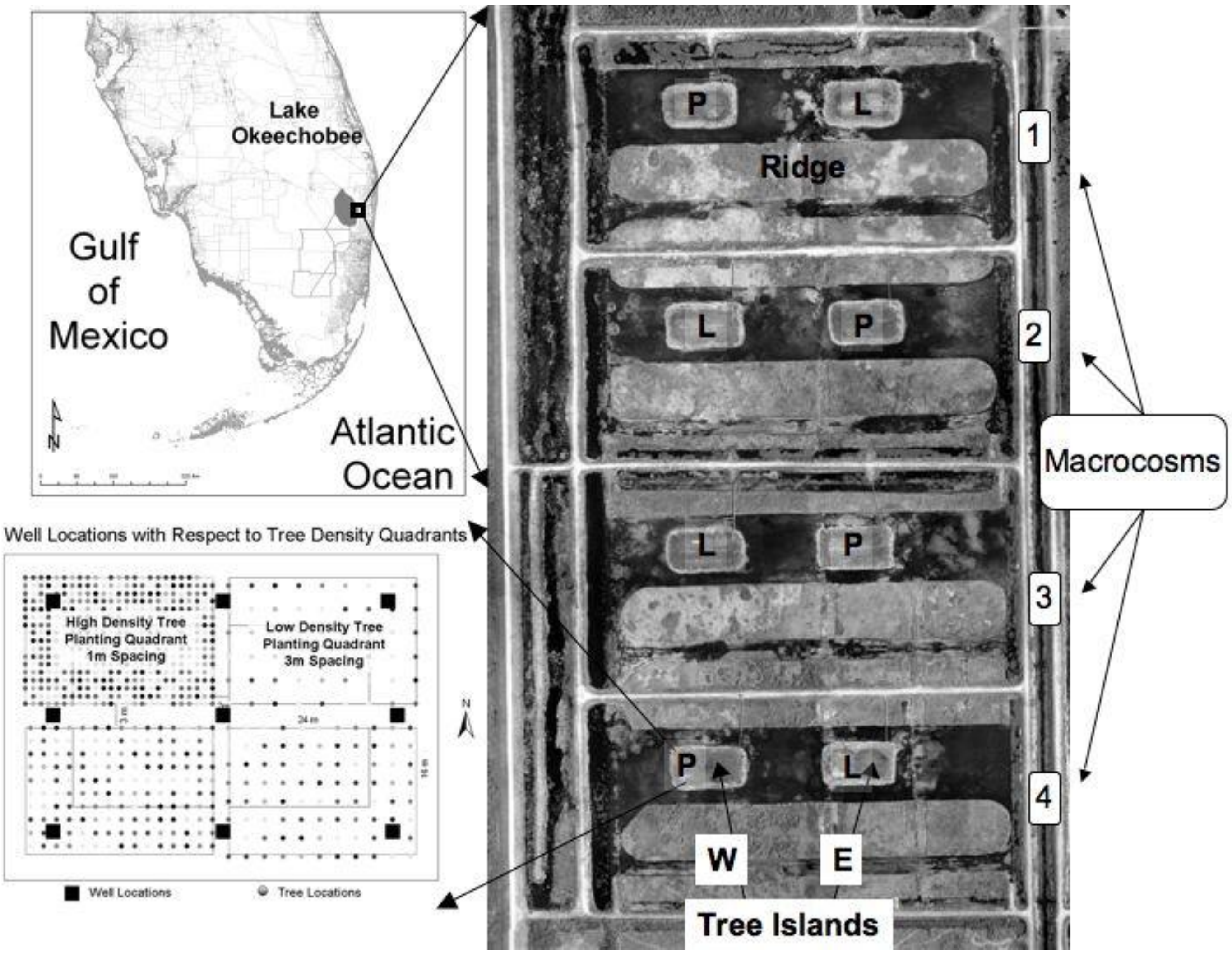


Figure 1. LILA is located in Loxahatchee National Wildlife Refuge (upper left). The aerial photograph (right) includes all four macrocosms within LILA and the corresponding base of each of the tree islands, the letter L signifies limestone while P signifies peat. The tree islands are planted in four different tree planting density (lower left), ranging from the high density quadrant with 1 m spacing between each of the trees to the low density quadrants with 3 m spacing between each of the trees.

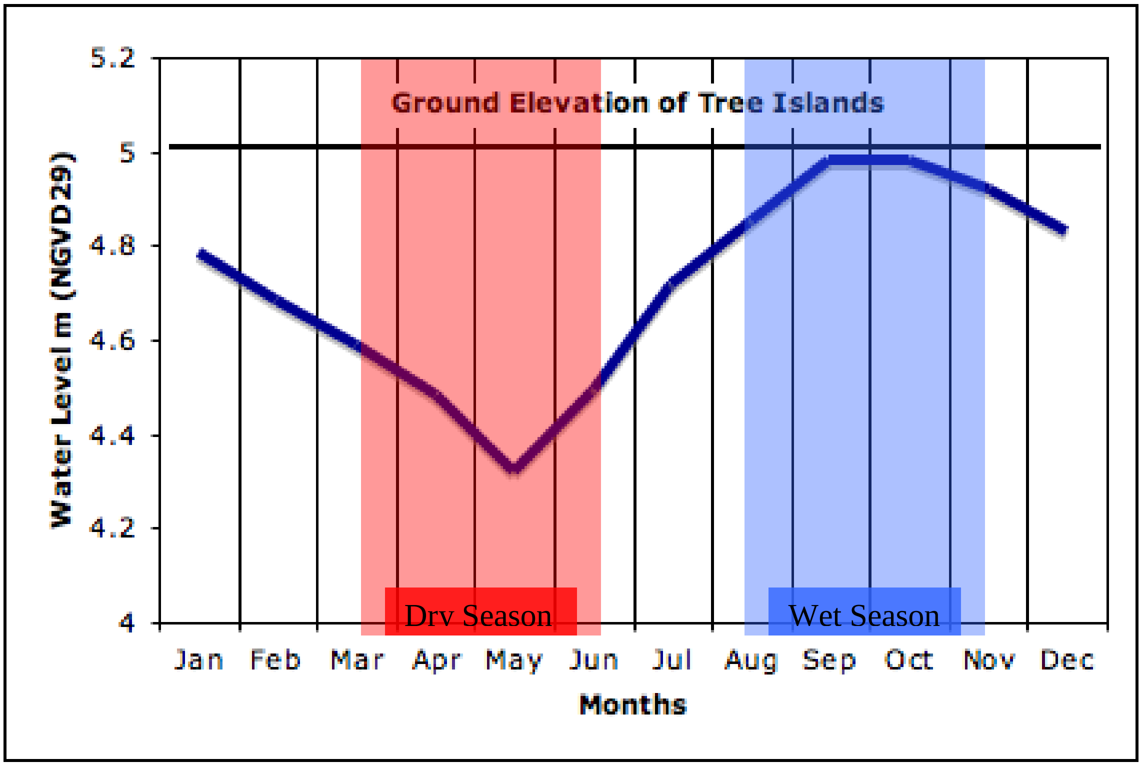


Figure 2. Operational schedule for surface water levels at LILA. In this study the dry and wet season are correlated to when surface water levels are low and surface water levels high.

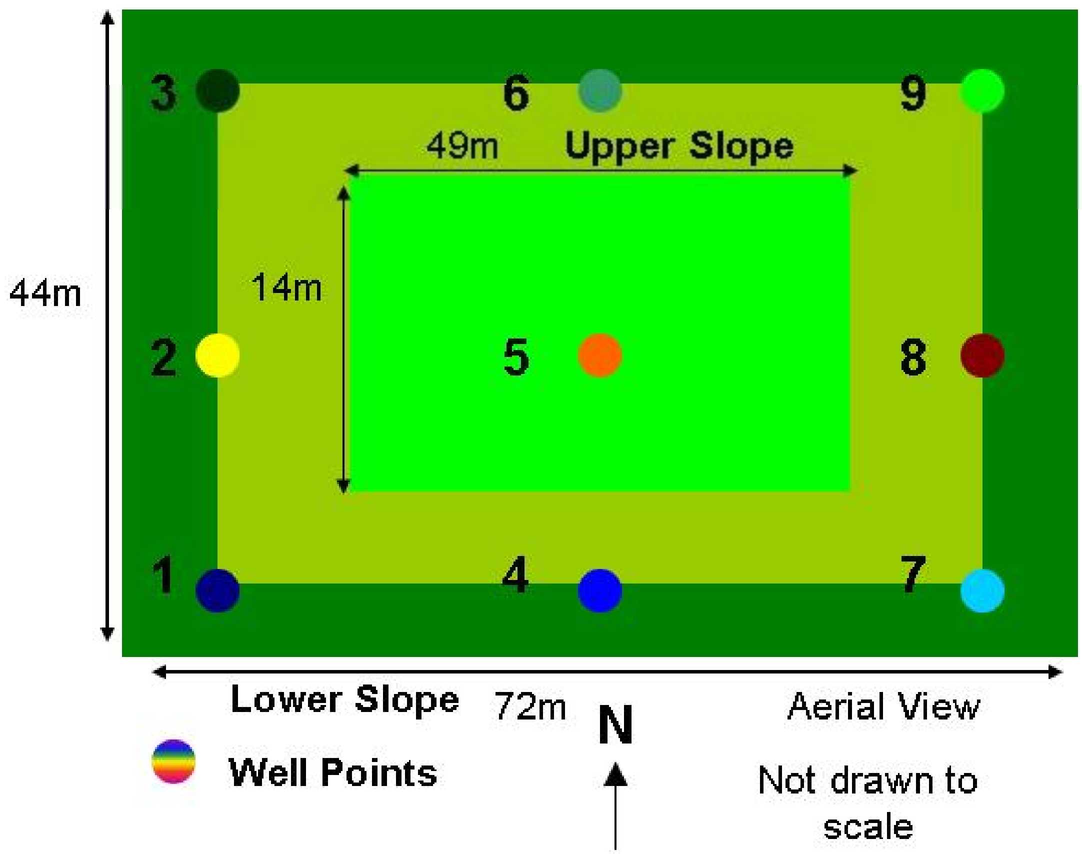


Figure 3. A diagram of well locations and numbering system for each tree island.

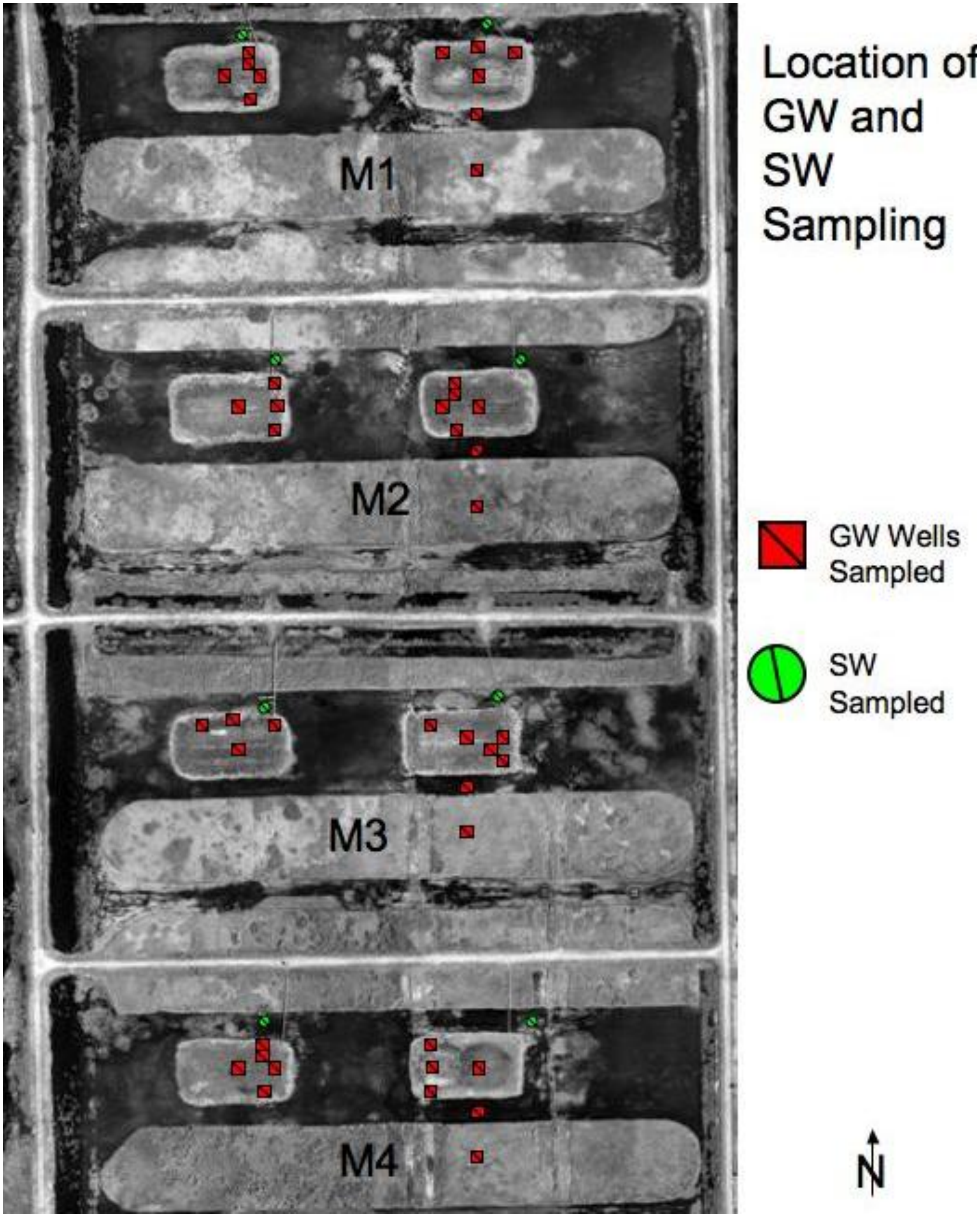


Figure 4. Location of groundwater wells (red) and surface water site (green) sampled in October 2008 and May of 2009.

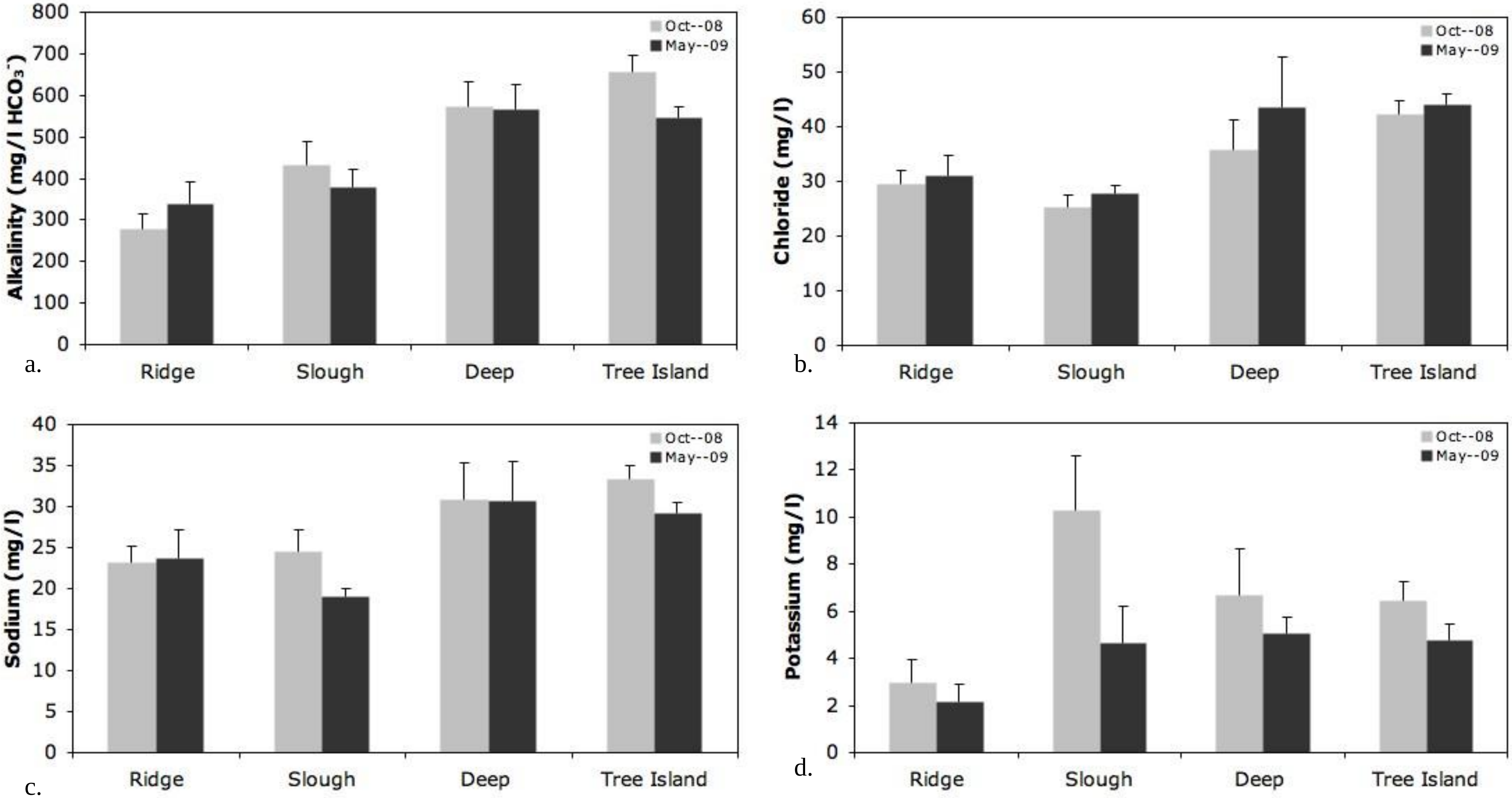


Figure 5. Average groundwater concentration and standard error of: a) alkalinity, b) chloride, c) sodium and d) potassium from the ridges, sloughs deep wells and tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

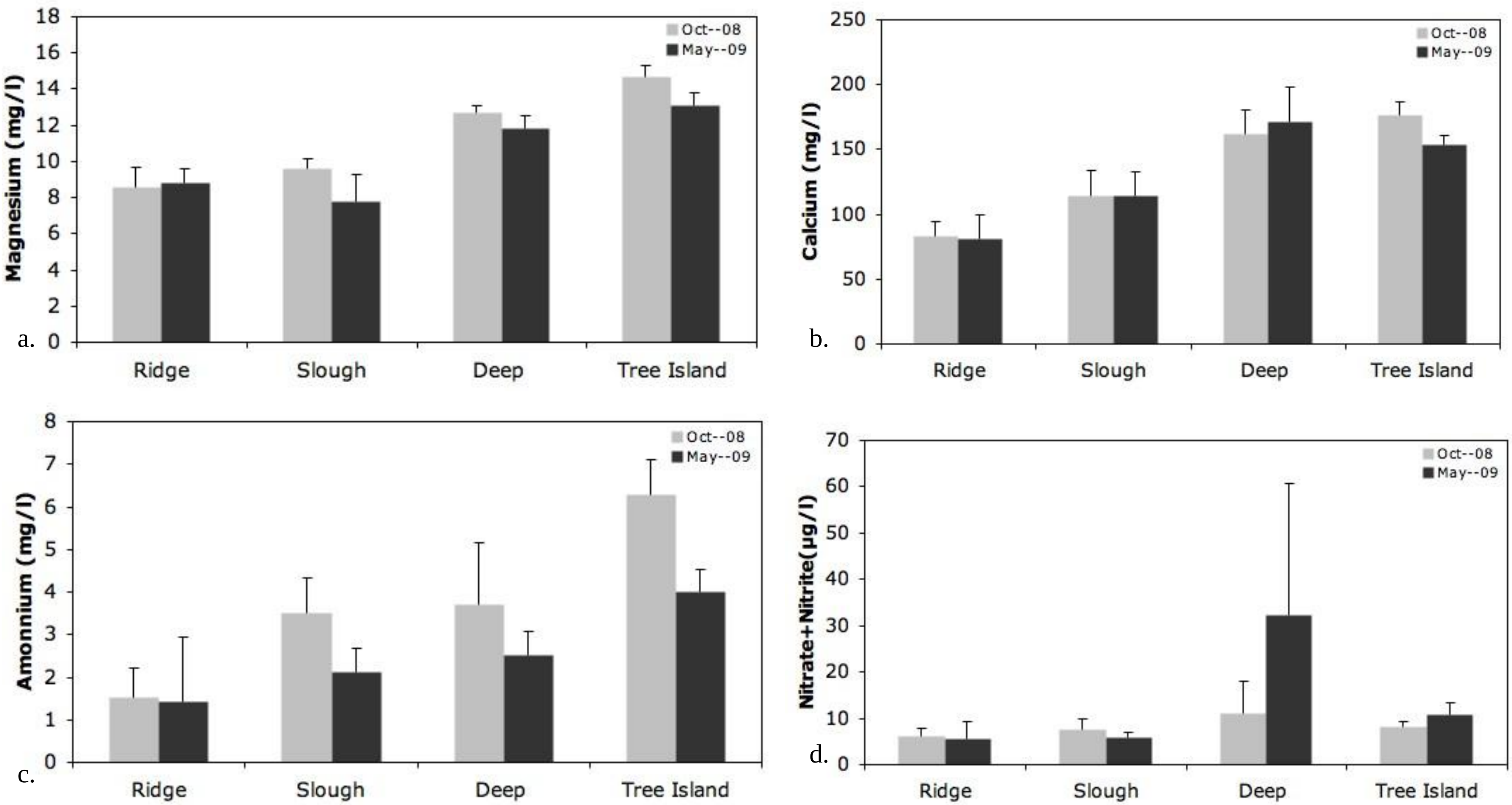


Figure 6. Average groundwater concentration and standard error of: a) magnesium, b) calcium, c) ammonium and d) nitrate+nitrite from the ridges, sloughs deep wells and tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

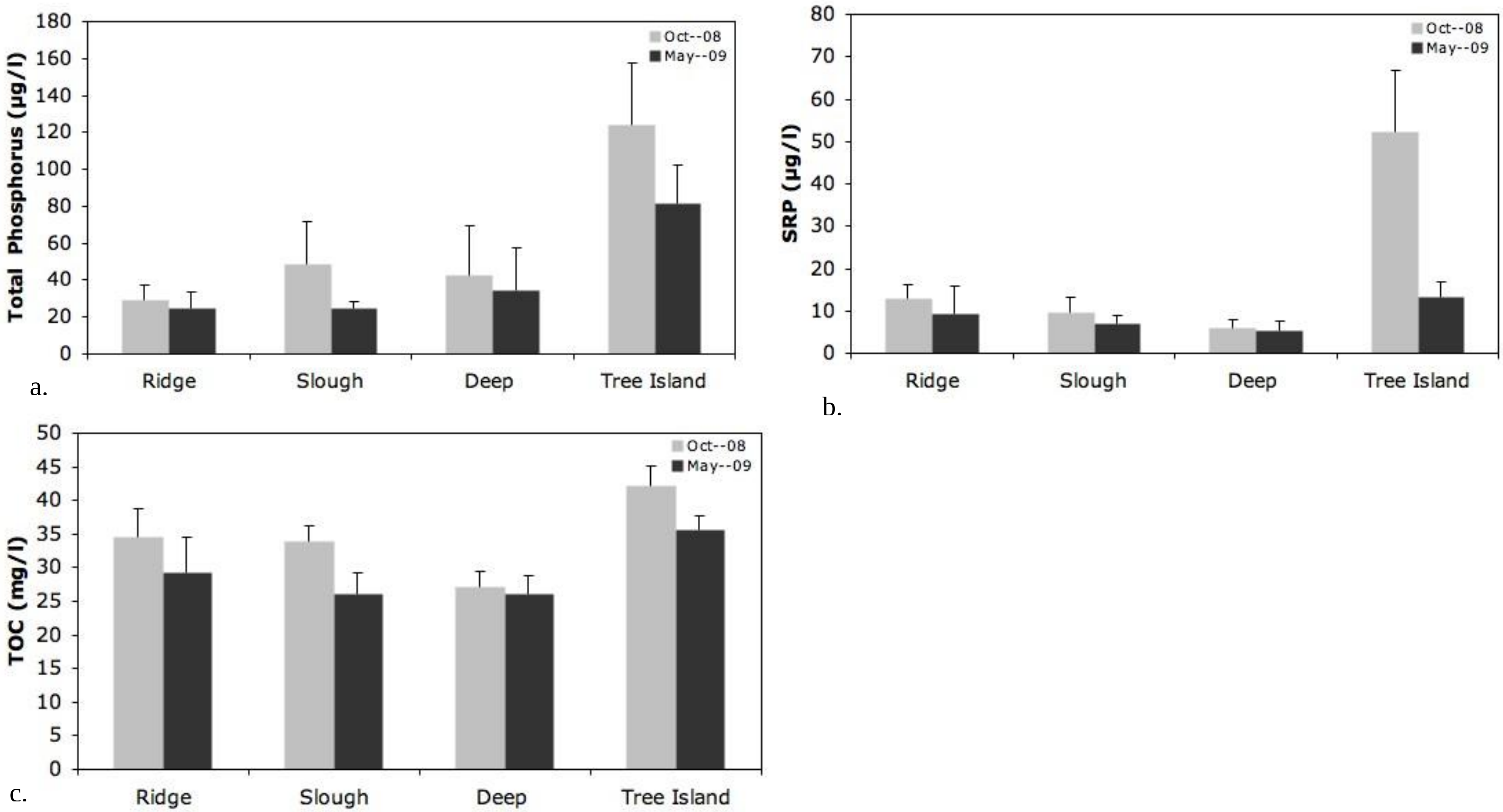


Figure 7. Average groundwater concentration and standard error of: a) total phosphors, b) soluble reactive phosphorus, and c) total organic carbon from the ridges, sloughs deep wells and tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

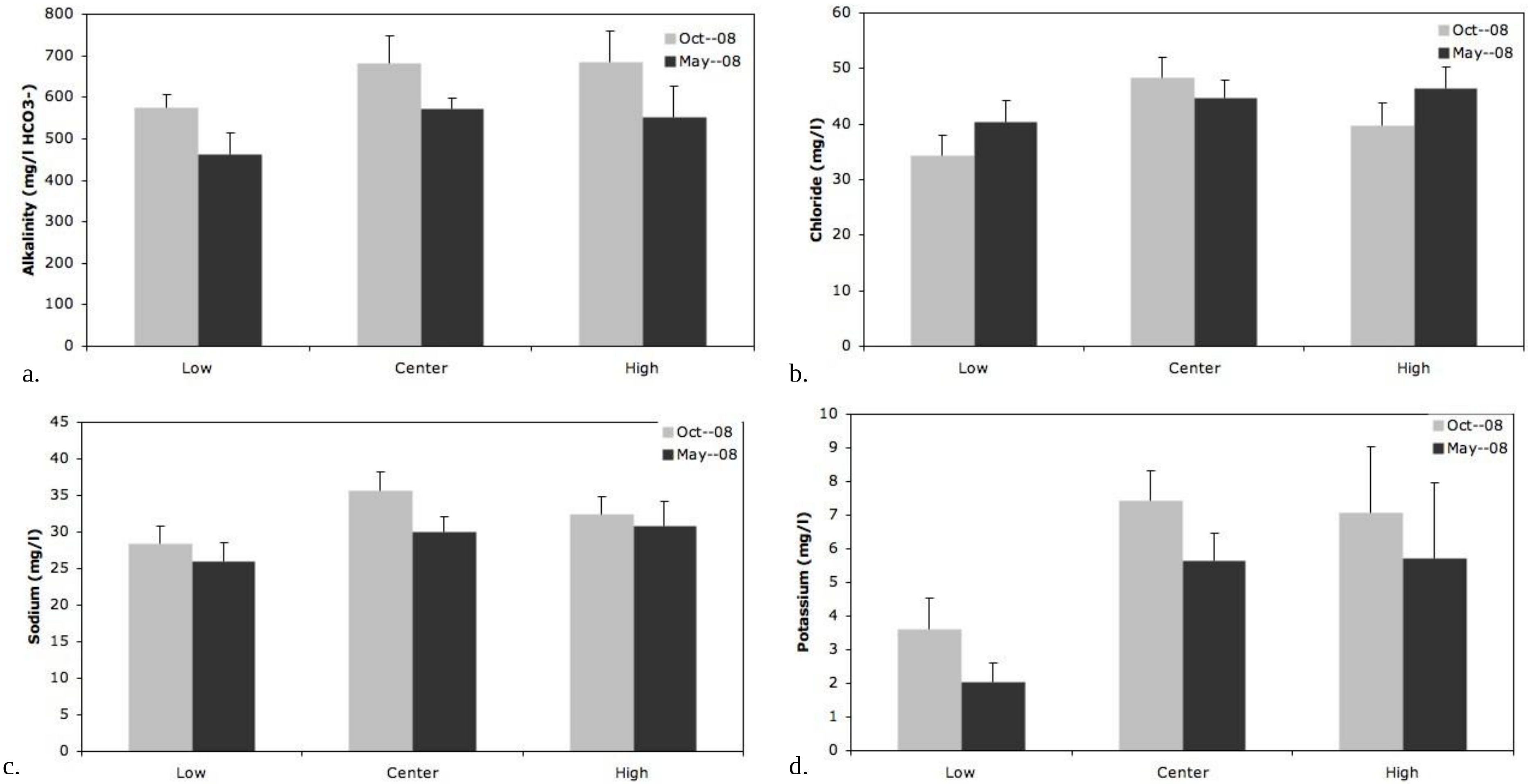


Figure 8. Average groundwater concentration and standard error of: a) alkalinity, b) chloride, c) sodium and d) potassium from the low and high density tree planting quadrants and the center of the tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

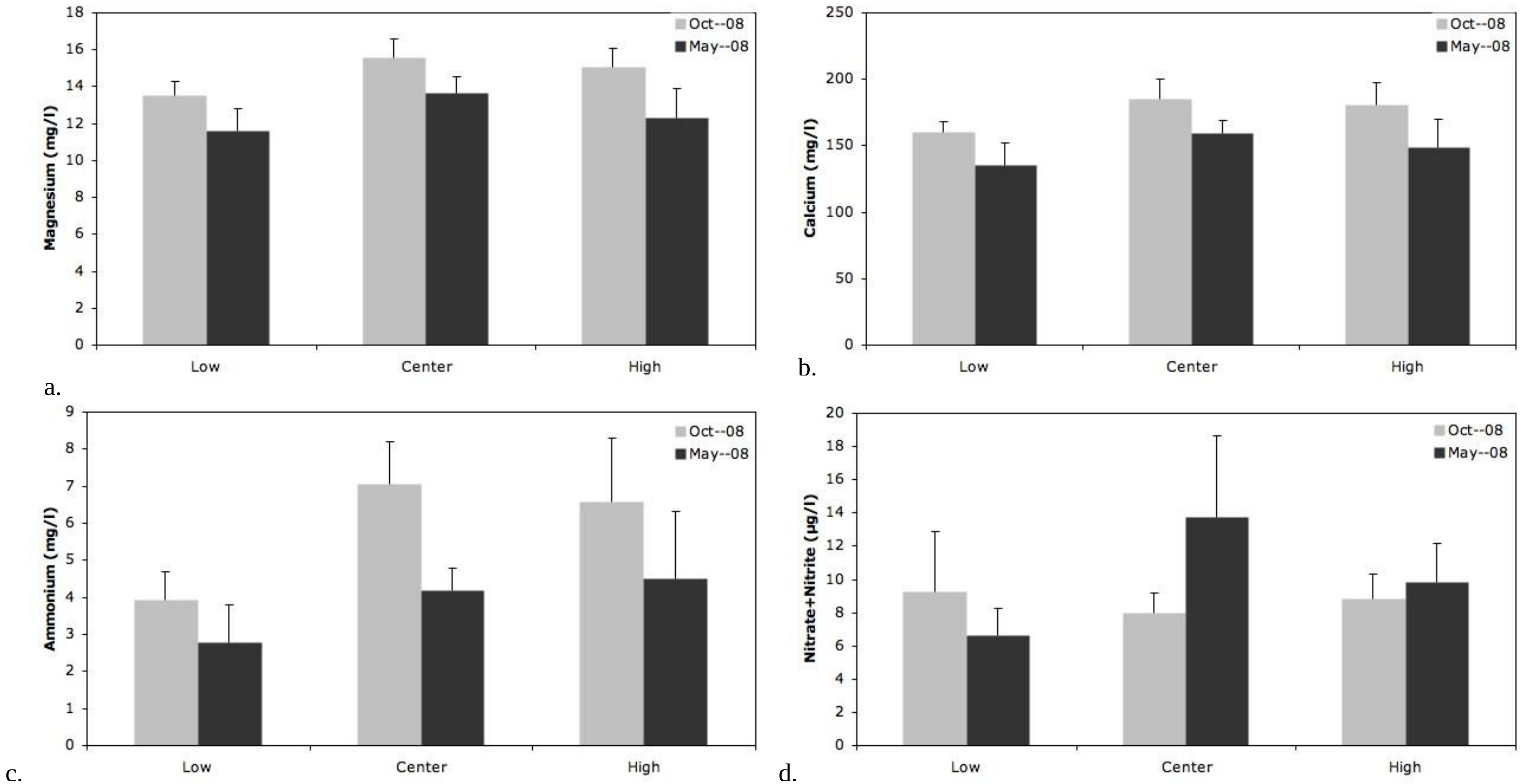


Figure 9. Average groundwater concentration and standard error of: a) magnesium, b) calcium, c) ammonium and d) nitrate+nitrite from the low and high density tree planting quadrants and the center of the tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

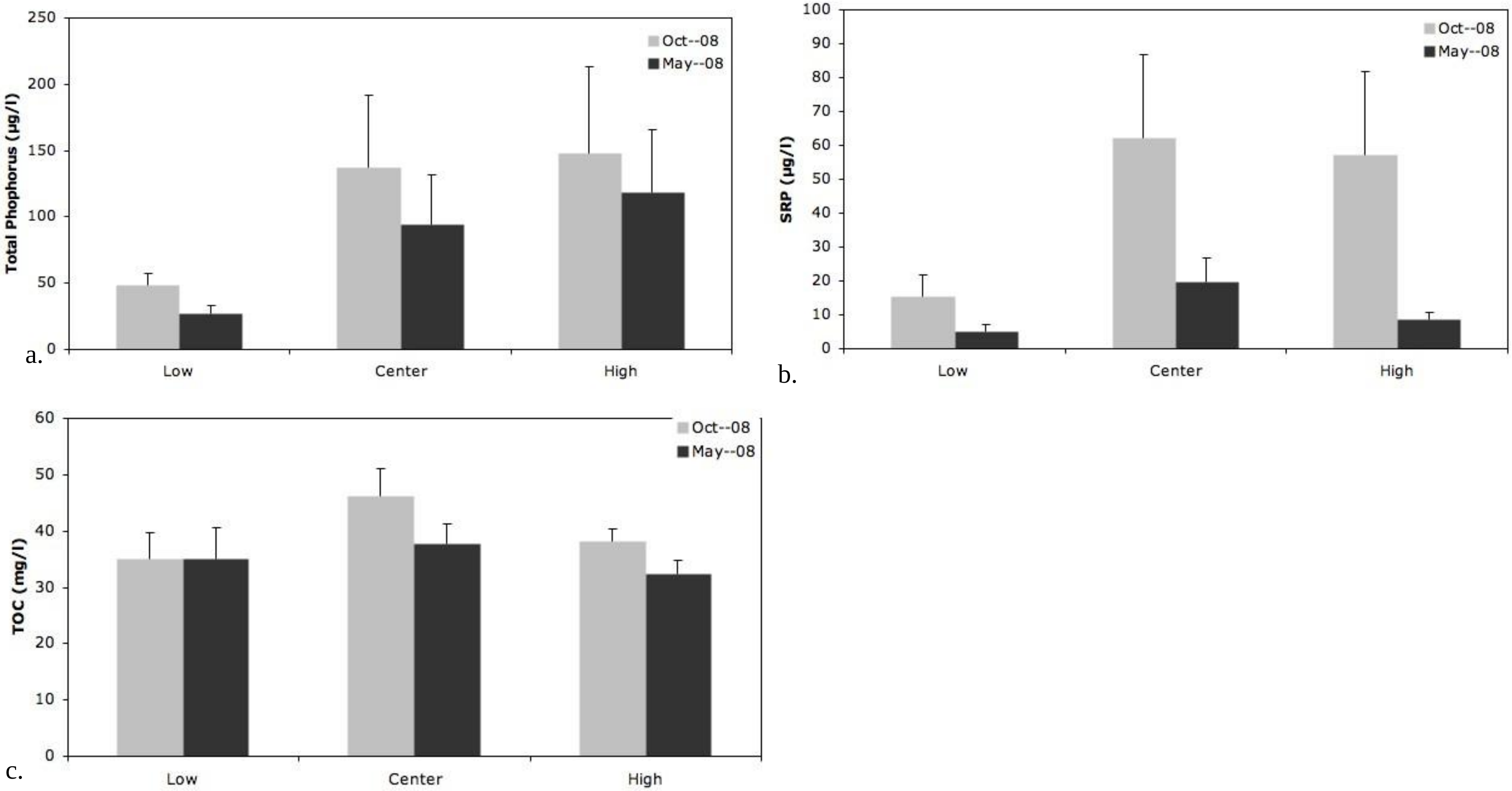
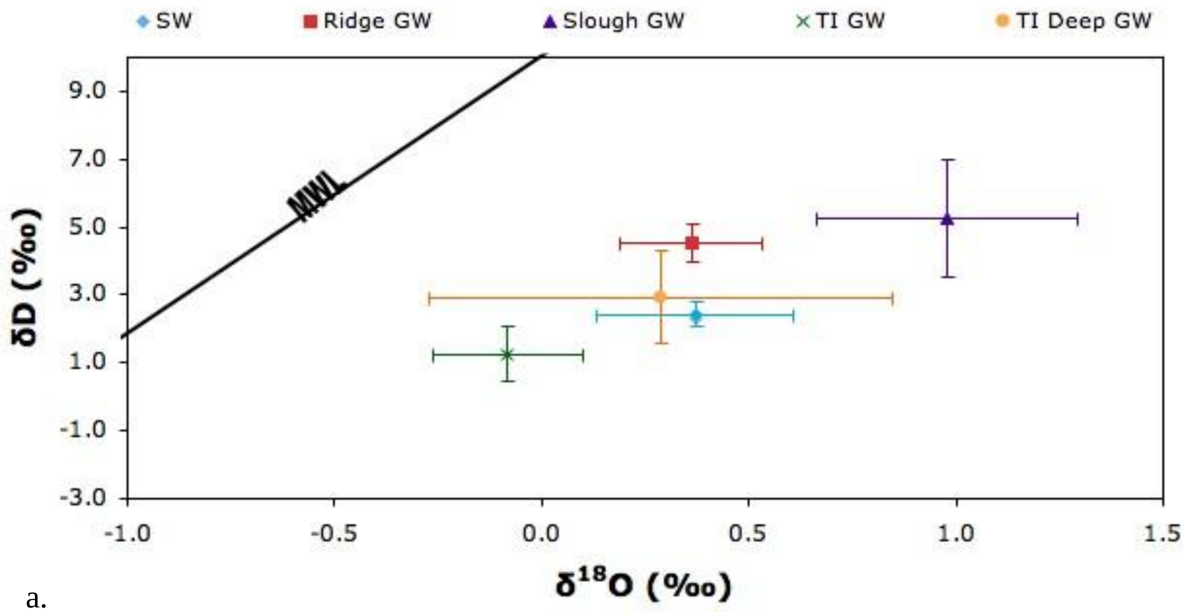
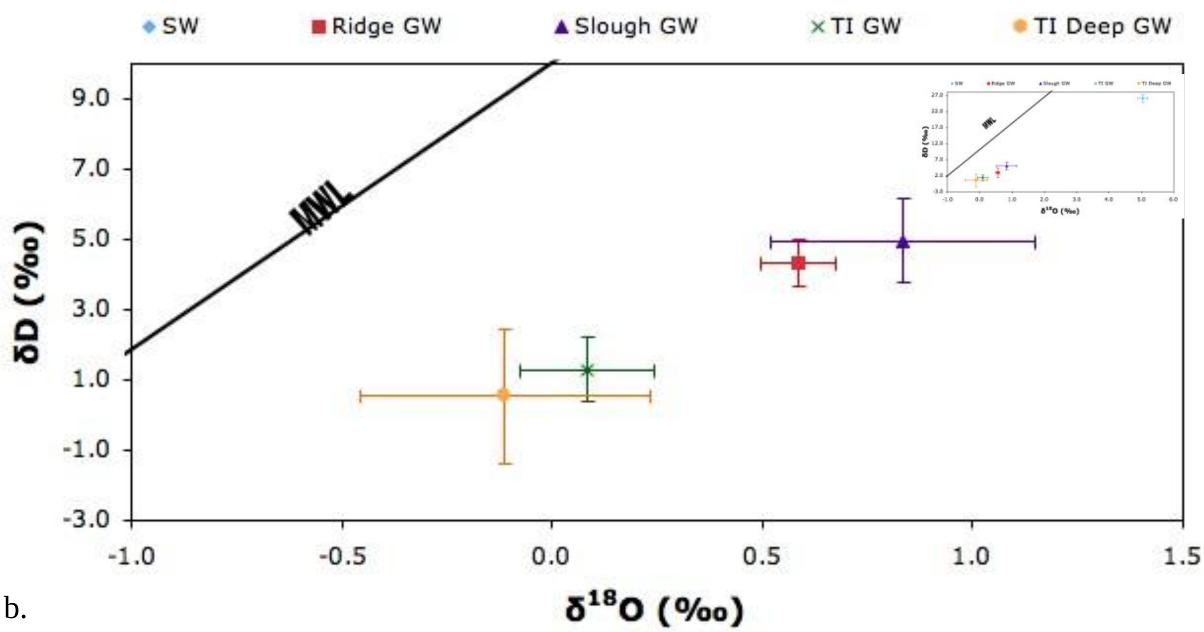


Figure 10. Average groundwater concentration and standard error of: a) total phosphorus, b) soluble reactive phosphors, and c) total organic carbon the low and high density tree planting quadrants and the center of the tree islands at LILA in the wet season (gray, Oct 2008) and the dry season (black, May 2009).

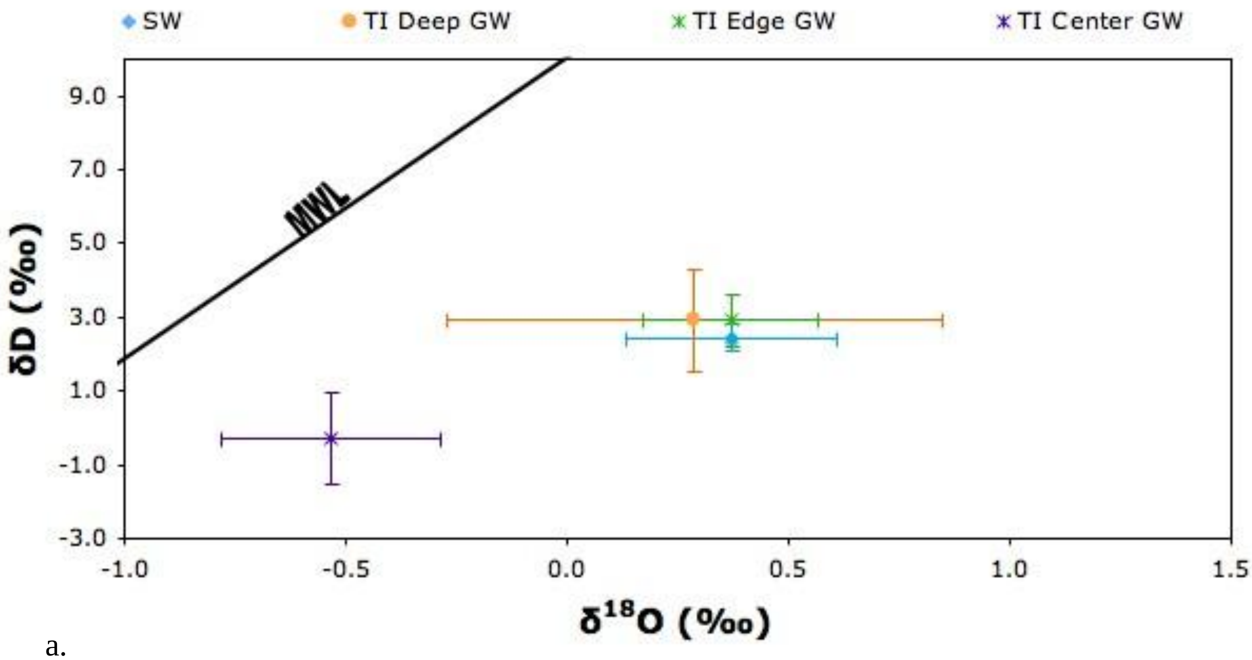


a.

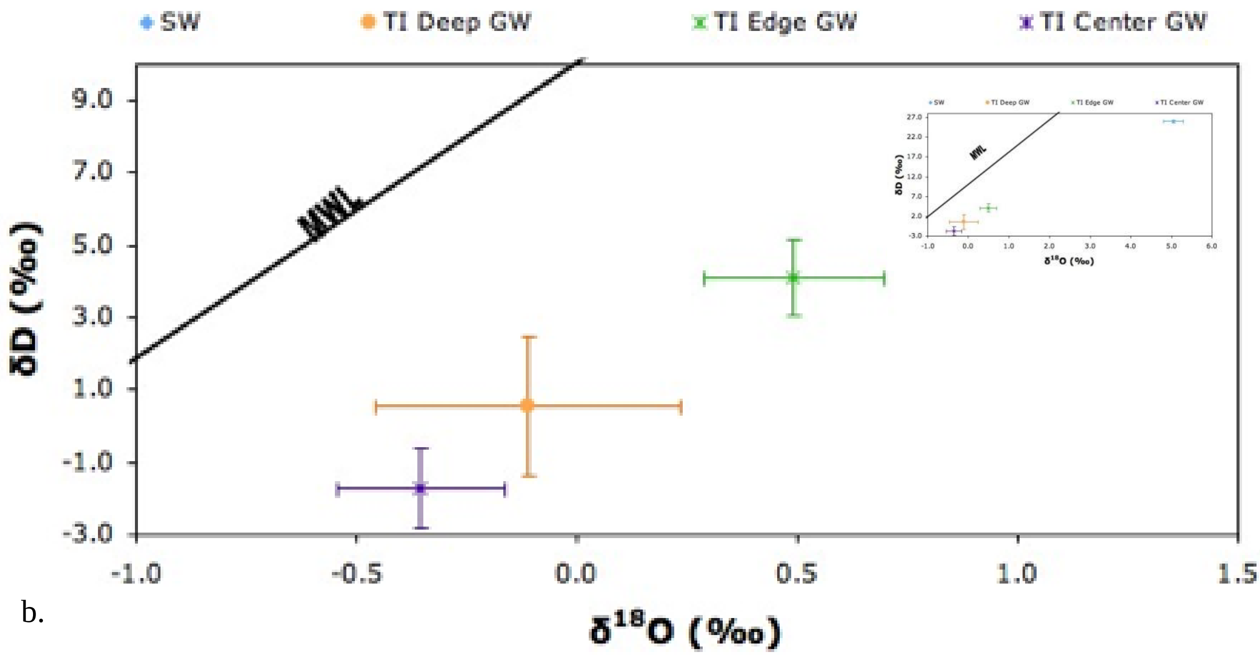


b.

Figure 11. The average isotopic values and standard error of deuterium and oxygen-18 of the surface water (blue) and groundwater from ridge (red), slough (purple), deep wells (orange) and tree islands (green) from: a) the wet season (October 2008) and b) the dry season (May 2009).



a.



b.

Figure 12. The average isotopic values and standard error of deuterium and oxygen-18 of the surface water (blue) and groundwater from center of the tree islands (purple), edges of the tree islands (green), and the deep wells (orange) from: a) the wet season (October 2008) and b) the dry season (May 2009).

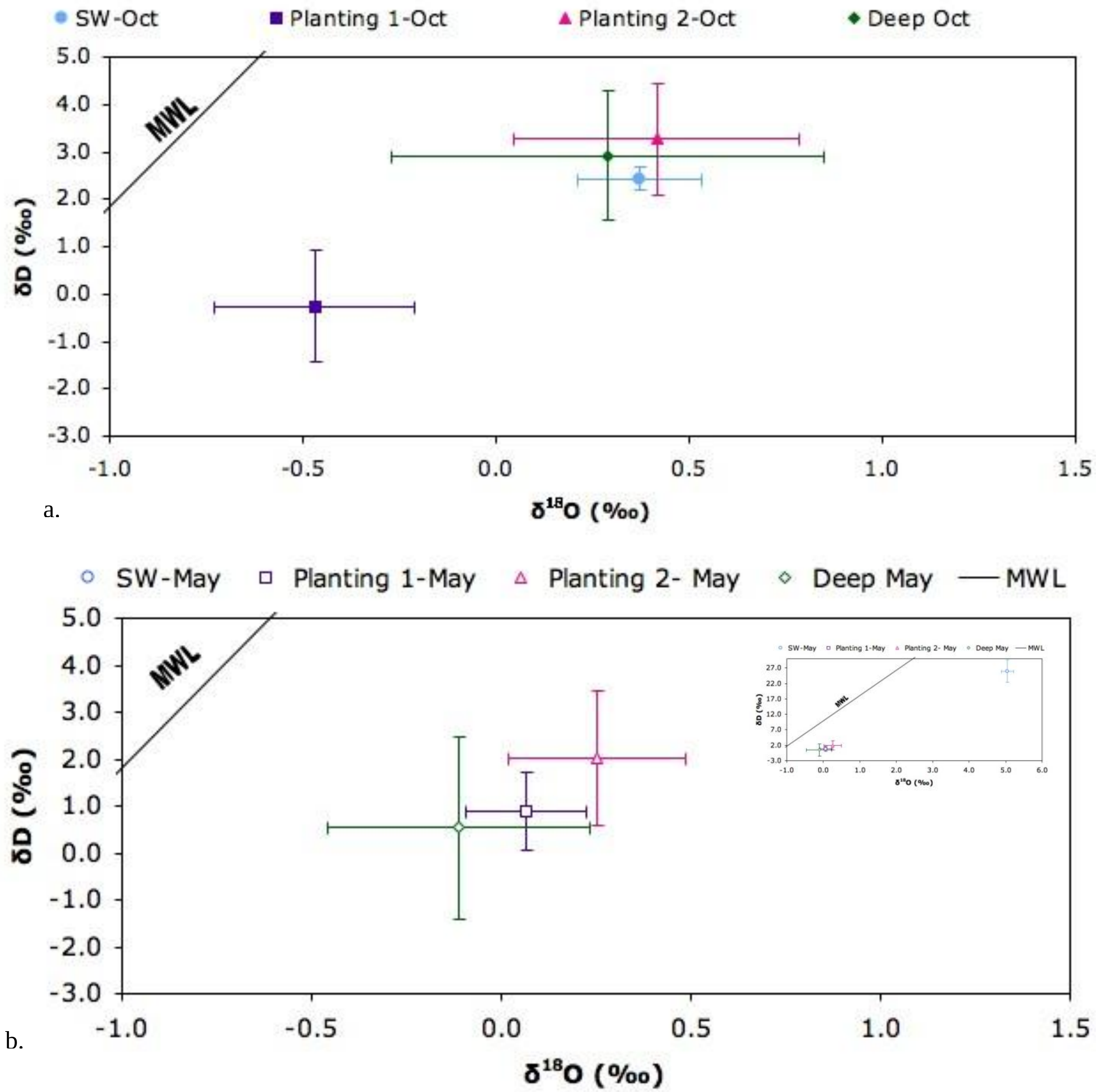


Figure 13. The average isotopic values and standard error of deuterium and oxygen-18 of the surface water (blue) and groundwater from Planting-1 (purple), tree islands planted in 2006, Planting-2 (pink), planted in 2007 and the deep wells (green) from: a) the wet season (October 2008, closed symbols) and b) the dry season (May 2009, open symbols).

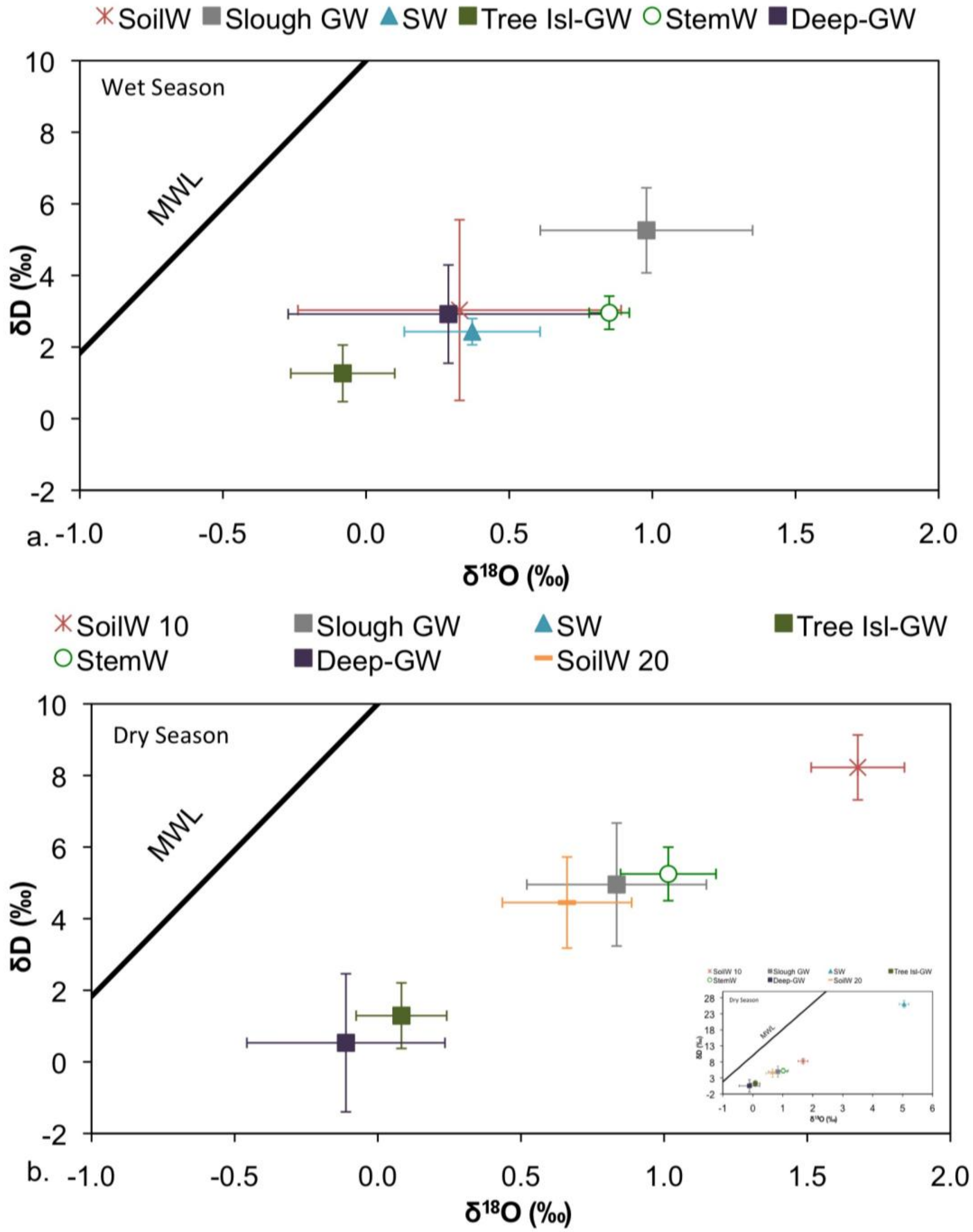


Figure 14. The average isotopic values and standard error of deuterium and oxygen-18 of the stem water (green circle) and soil water as compared to isotopic composition of the surface water and groundwater from the tree islands, slough and deep wells for the wet season (a.) and dry season (b.). During the dry season soil water samples were collected at 10 cm and 20 cm of depth while during

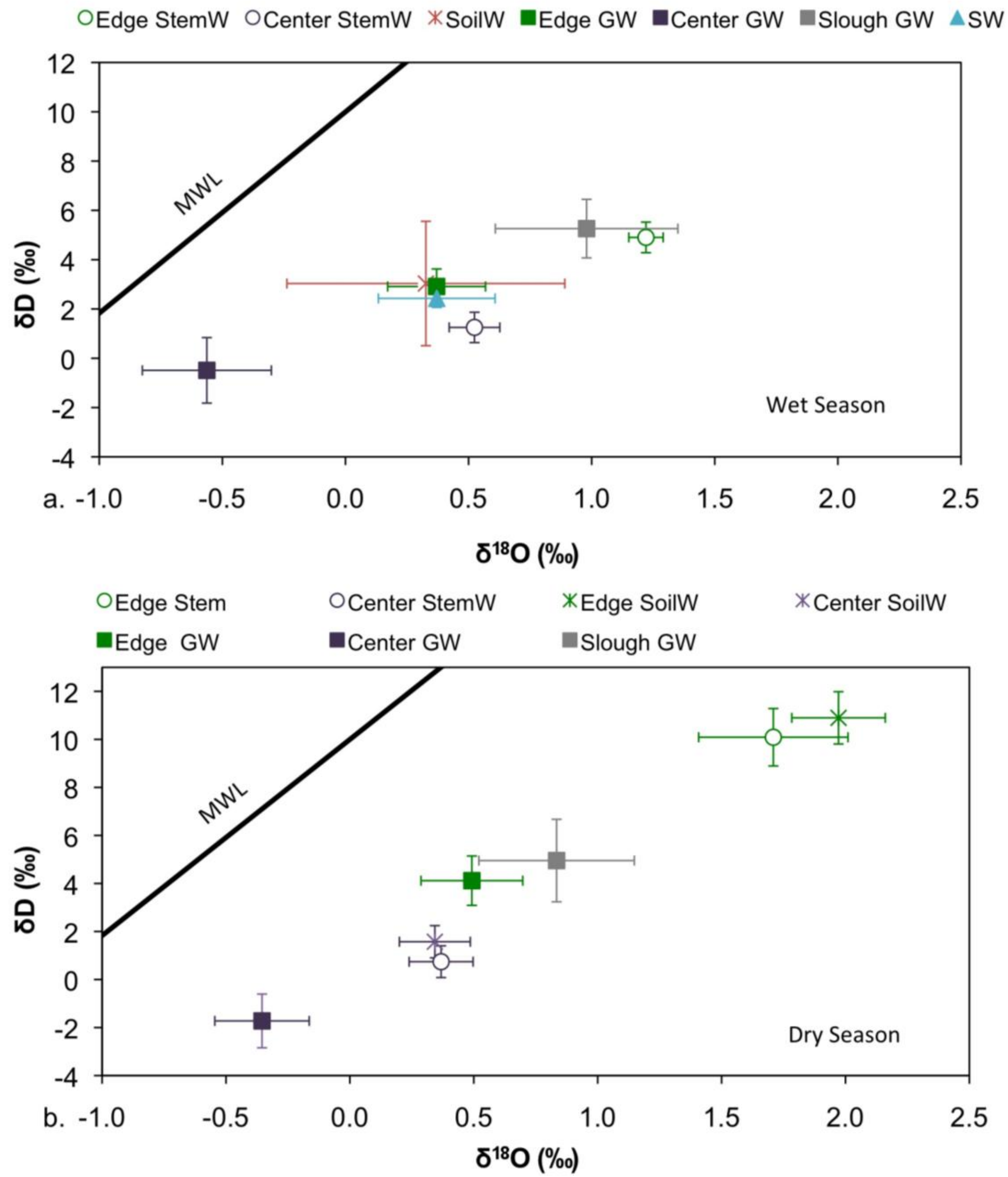


Figure 15. The average isotopic values and standard error of deuterium and oxygen-18 of the stem water (open circle), soil water (cross hatch) and groundwater (square) from the center (purple) and edge (green) of the islands from the wet season (a.) and dry season (b.).

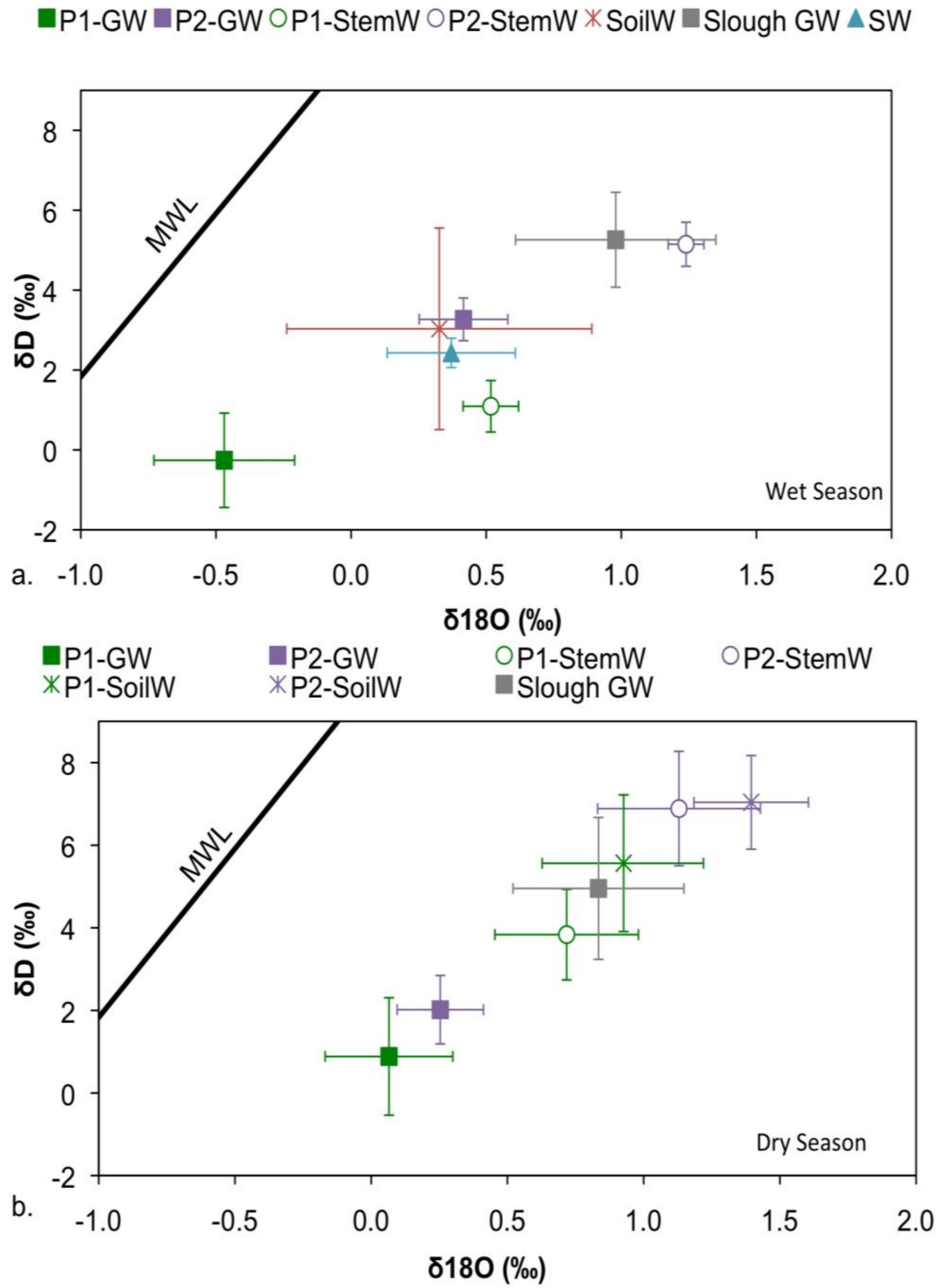


Figure 16. The average isotopic values and standard error of deuterium and oxygen-18 of the stem water (open circle), soil water (cross hatch) and groundwater (square) from tree islands planted in 2006 (green, P1) and 2007 (purple, P2) in the wet season (a.) and dry season (b.).

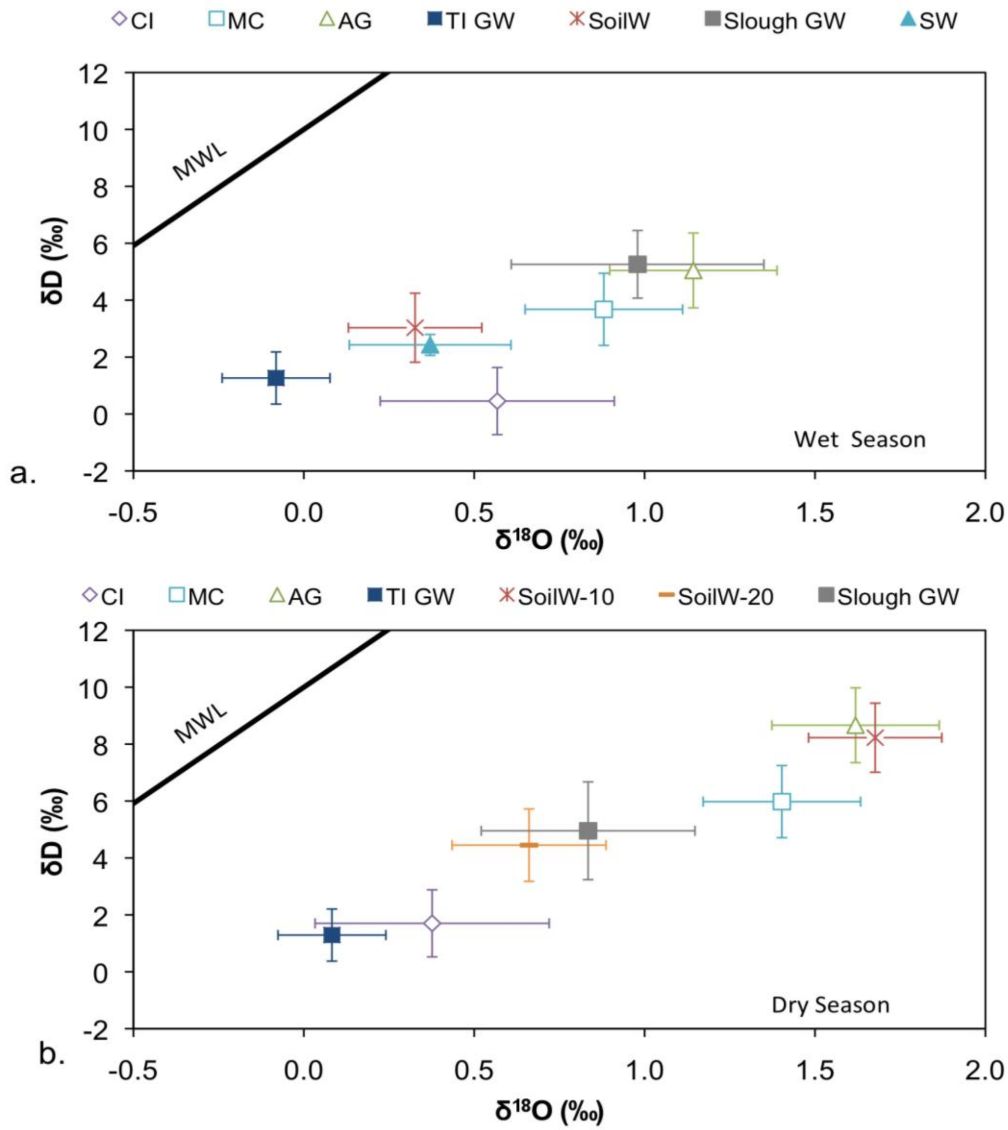


Figure 17. The average isotopic values and standard error of deuterium and oxygen-18 of the soil water (cross hatch), groundwater (square), stem water (open symbols). During the wet season (a.) and dry season (b.) the average isotopic composition of the *Chrysobalanus iaco* (*CI*) was significantly depleted as compared to *Annona glabra* (*AG*) , *Myrica cerifera* (*MC*) was signficantly enriched as compare to *CI* during the dry season.

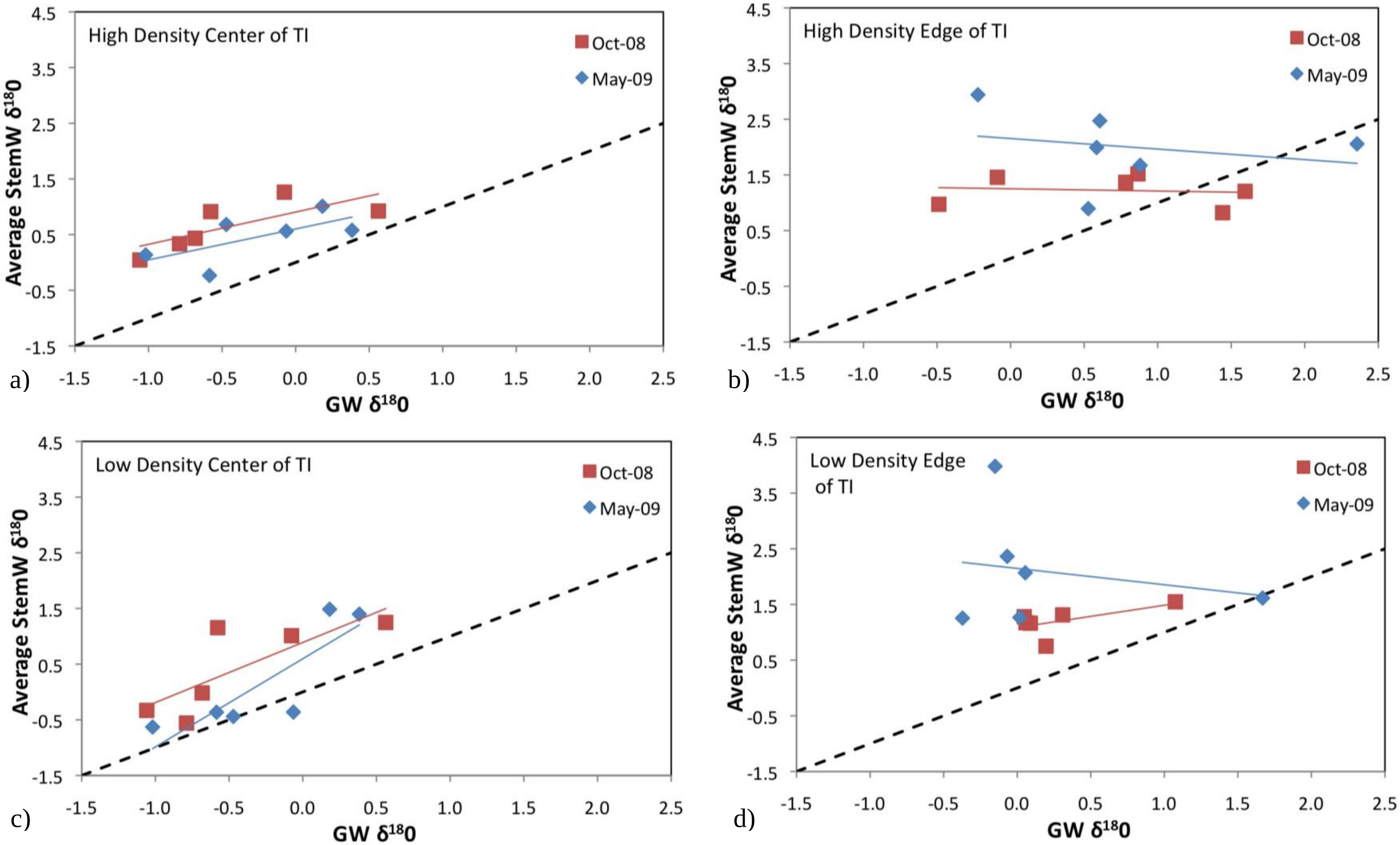


Figure. 18. The average oxygen-18 stem water and groundwater values for wet season (red) and dry season (blue) of 2008-2009; a) the high density high elevation, b) the high density low elevation, c) the low density high elevation and d) the high density low elevation. If the slope of the regressions matched the one-to-one line (dashed) it would indicate that the trees were relying solely on groundwater.

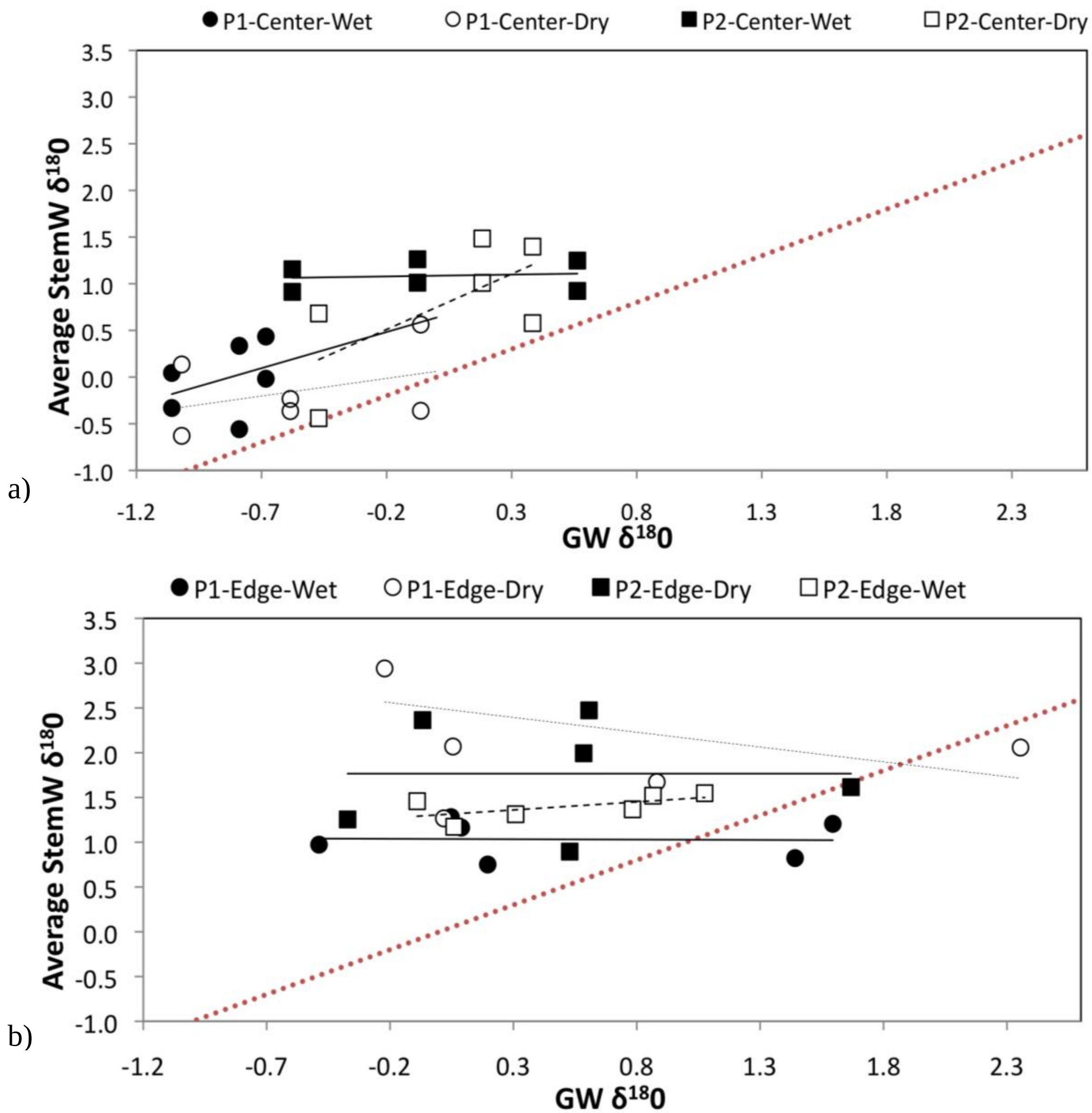


Figure 19. The average oxygen-18 stem water and groundwater values for Planting-1 (circle) and Planting-2 (square) during the wet season (black) and dry season (hollow) of 2008-2009; a) center of the islands and b) the edge of the islands. If the slope of the regressions matched the one-to-one line (dashed) it would indicate that the trees were relying solely on groundwater.

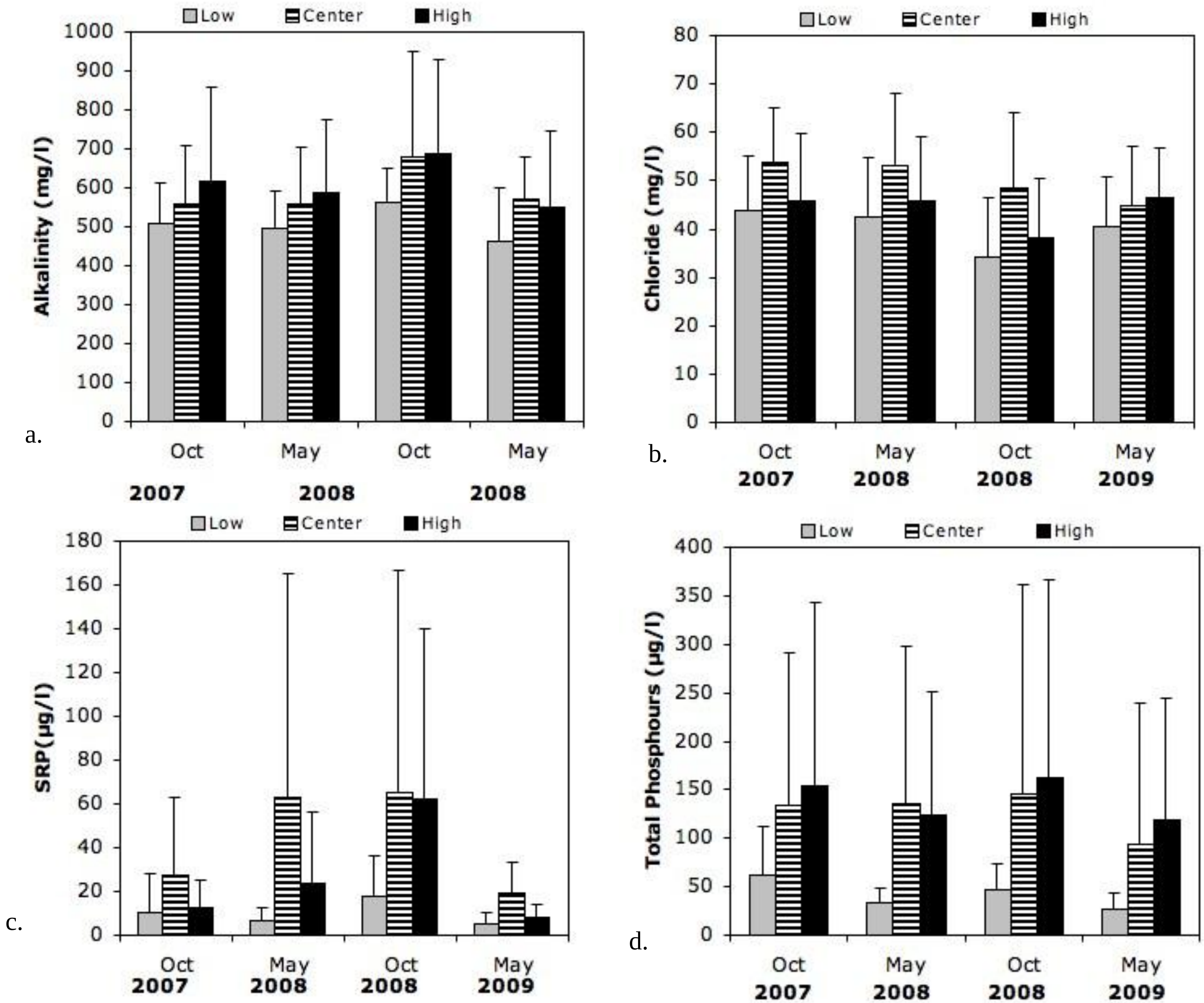


Figure 20. Groundwater concentrations of: a) alkalinity, b) chloride, c) soluble reactive phosphorus and d) total phosphorus in the low (gray) and high (black) density tree planting quadrants and the center (hatched) of the tree islands for wet and dry sampling events from October 2007 through May 2009.

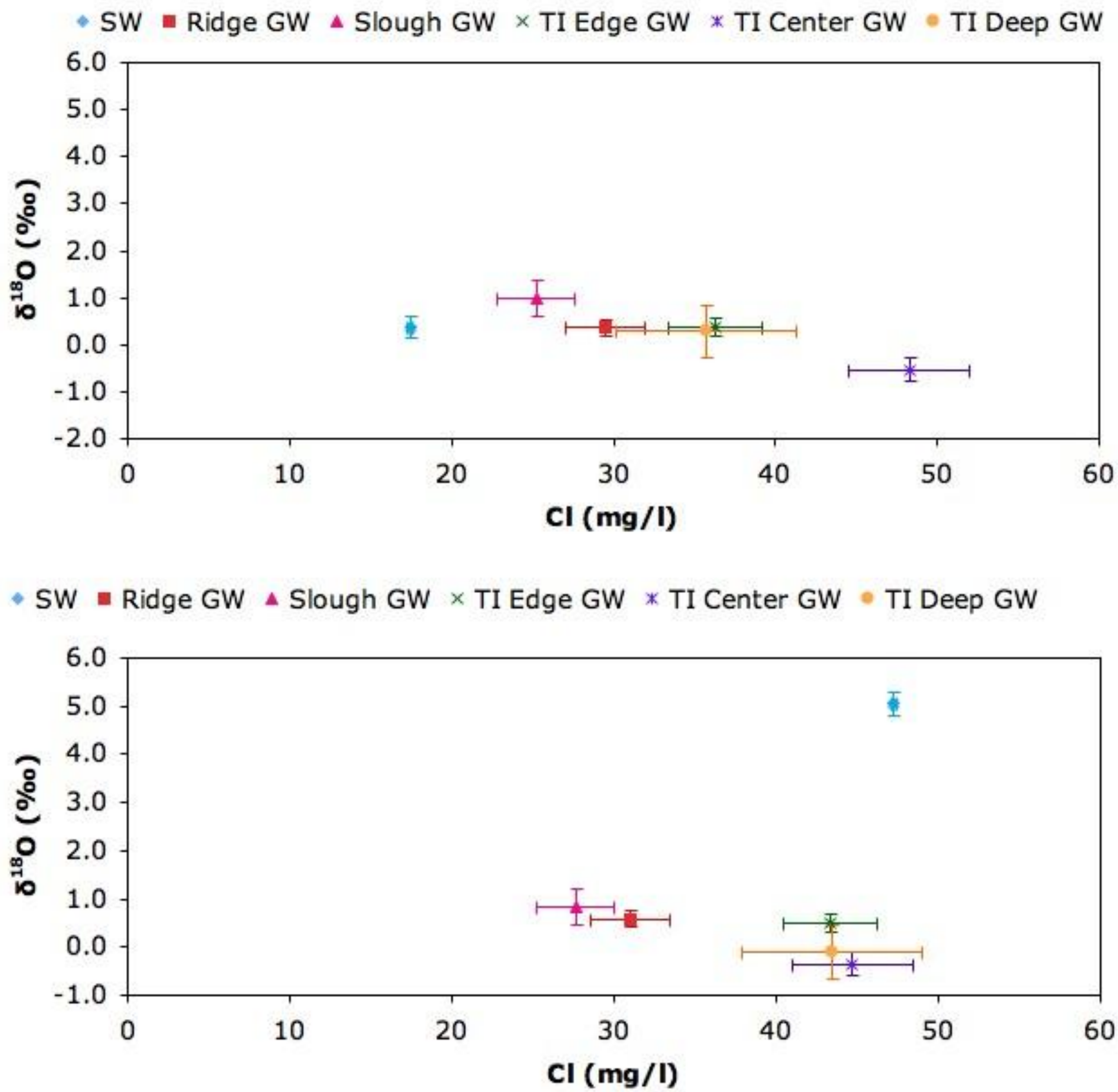


Figure 21. Average oxygen-18 values and chloride concentrations for surface water (blue) and groundwater from ridge (red), slough (purple), deep wells (orange) and tree islands (green) from: a) the wet season (October 2008) and b) the dry season (May 2009). Error bars represent standard error.

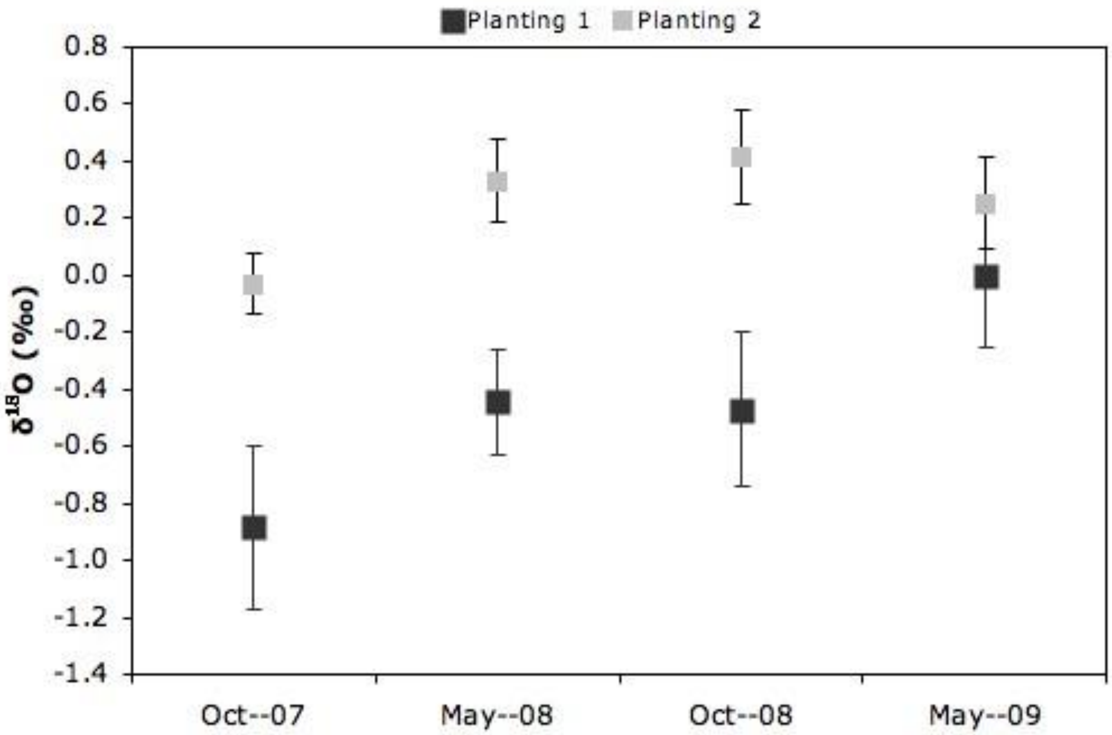


Figure 22. The average oxygen-18 values of the groundwater from islands planted in 2006 (Planting-1) and 2007 (Planting-2).